EXHIBIT A

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Voto et al.

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(54) **FLEXIBLE MOBILE DEVICE CONNECTIVITY TO AUTOMOTIVE SYSTEMS WITH USB HUBS**

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(Continued)

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G06F 13/40 (2006.01)
G06F 13/38 (2006.01)

(52) **U.S. Cl.**

CPC ***G06F 13/4022*** (2013.01); ***G06F 13/385*** (2013.01); *G06F 13/4045* (2013.01)

(58) **Field of Classification Search**

CPC G06F 13/4022; G06F 13/4045; G06F 13/385; G06F 13/387; G06F 13/366;

(Continued)

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,073,188 A 6/2000 Fleming
6,732,219 B1 5/2004 Broyles

(Continued)

FOREIGN PATENT DOCUMENTS

JP 2003256351 A 9/2003
TW 470887 B 1/2002

OTHER PUBLICATIONS

"FFI Rapport—A Study of Computer Interfaces for Soldier Systems", Lars Erik Olsen & Joakin Flathagen, Norwegian Defence Research Establishment, Oct. 10, 2005.

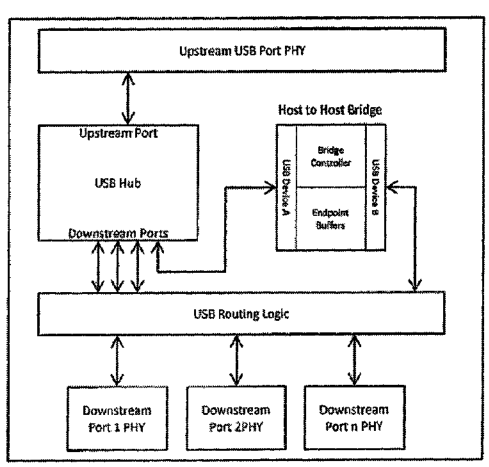
(Continued)

Primary Examiner — Ernest Unelus
(74) *Attorney, Agent, or Firm* — Robert J. Myers

(57) **ABSTRACT**

A system which is configured to enable a vehicle's embedded USB Host system to connect to multiple mobile devices through a USB Hub, regardless of whether the mobile devices are configured to act as USB Hosts or USB Devices, without the need to add or provide OTG controllers in the system or additional vehicle wiring, or inhibiting the functionality of any consumer devices operating in USB Device mode connected to a vehicle system Hub while another consumer device connected to the same Hub operates in USB Host mode. Preferably, the system is configured to provide that no additional cabling is required, and no hardware changes are required to be made to the HU. The system can be employed between a vehicle's embedded USB Host, USB Hub and at least one consumer accessible USB port. In the case where the consumer device is acting as a USB Host, signals between the consumer device and the vehicle's embedded USB Host are processed through a bridge, thereby rendering the consumer device compatible with the vehicle's embedded USB Host.

20 Claims, 8 Drawing Sheets



Related U.S. Application Data

(60) Provisional application No. 61/882,915, filed on Sep. 26, 2013.

(58) **Field of Classification Search**
CPC G06F 13/4068; G06F 13/4282; G06F 13/4027; G06F 2213/0042
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,934,793	B2	8/2005	Ying et al.
6,957,287	B2	10/2005	Lou et al.
7,130,656	B2	10/2006	Okagaki et al.
7,280,802	B2	10/2007	Grady
7,478,191	B2	1/2009	Wurzburg et al.
7,523,243	B2	4/2009	Bohm et al.
7,627,708	B2	12/2009	Bohm et al.
8,447,598	B2	5/2013	Chutorash et al.
8,447,890	B1	5/2013	LeTourneur et al.
2003/0167345	A1	9/2003	Knight et al.
2006/0056401	A1	3/2006	Bohm et al.
2007/0067553	A1	3/2007	Chang
2007/0086724	A1	4/2007	Grady et al.
2007/0156293	A1	7/2007	Kellzi et al.
2008/0005262	A1	1/2008	Wurzburg et al.
2009/0117890	A1	5/2009	Jacobsen et al.
2011/0054721	A1	3/2011	Goodrich et al.
2011/0124300	A1	5/2011	Sinai
2011/0208891	A1 *	8/2011	Meyers G06F 13/385 710/313
2011/0208892	A1 *	8/2011	Meyers G06F 13/4226 710/313
2012/0134506	A1	5/2012	DeBiasio et al.
2012/0191811	A1	7/2012	Ng et al.
2012/0290859	A1	11/2012	Saladin et al.
2013/0053003	A1	2/2013	King, II
2013/0106750	A1	5/2013	Kurosawa
2016/0132448	A1 *	5/2016	Maung G06F 13/366 710/104

OTHER PUBLICATIONS

"USB 2.0 Autoswitch User's Manual", Lindy Electronics Limited & Lindy-Elektronic GMBH, Sep. 2002.

"APC USB 2.0 Host Controller—Device Driver Download", http://www.liutilities.com/devicedriver/apcusb20hostcontroller/, Jul. 2002.

"Peripheral-Sharing Hardware Suits Education's Needs to a 'T'", Terian Tyre, T H E Journal (Technological Horizons in Education), Oct. 1988.

* cited by examiner

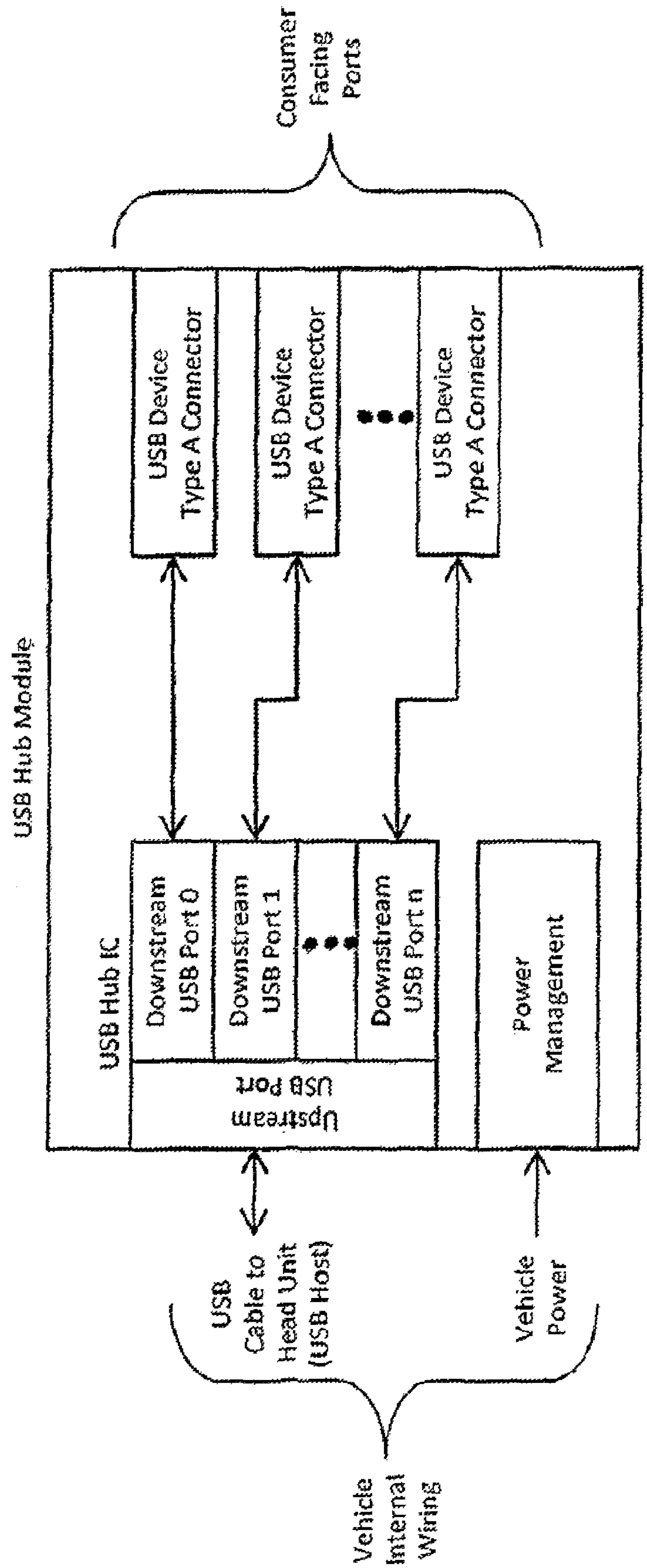

Consumer Facing Ports
USB Device Type A Connector
USB Device Type A Connector
USB Device Type A Connector
USB Hub Module
USB Hub IC
Downstream USB Port 0
Downstream USB Port 1
Downstream USB Port n
Upstream USB Port
Power Management
USB Cable to Head Unit (USB Host)
Vehicle Power
Vehicle Internal Wiring

Figure 1

Figure 2

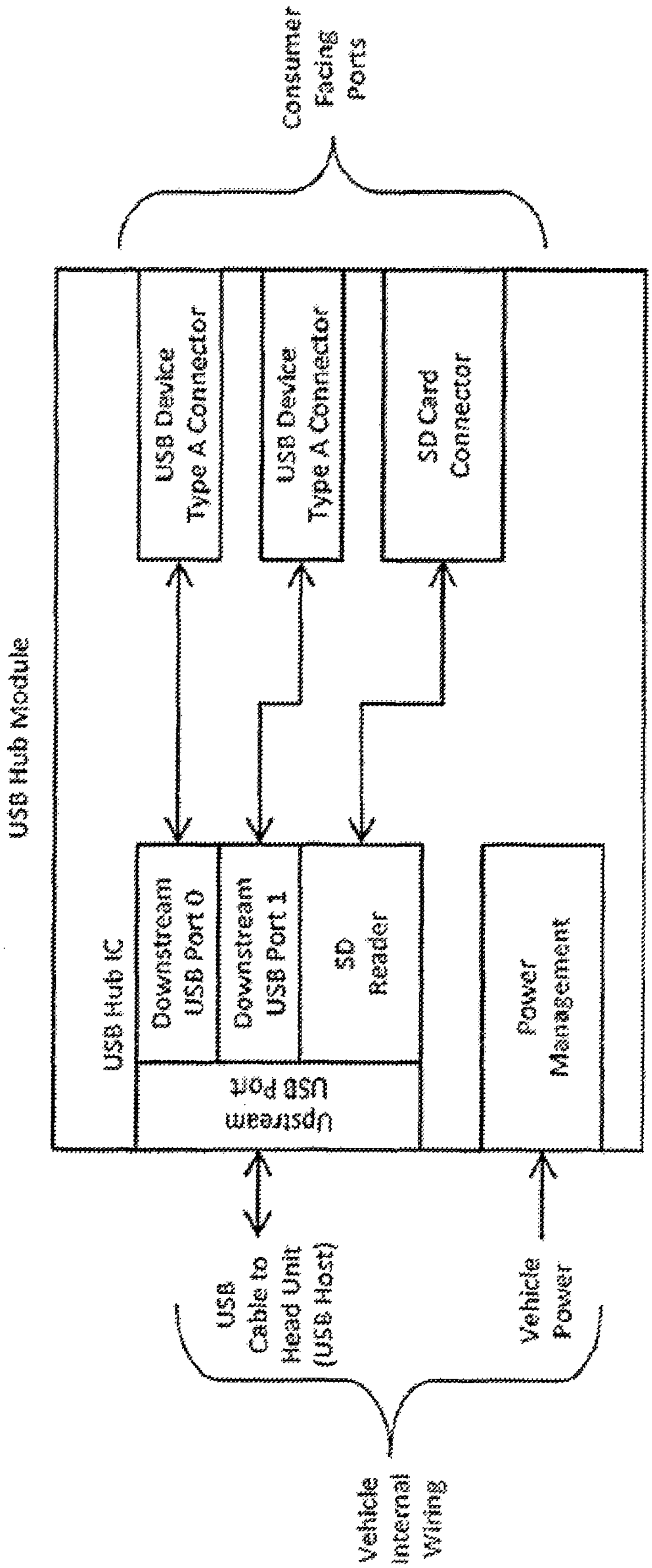

Consumer Facing Ports
USB Hub Module
USB Device Type A Connector
USB Device Type A Connector
SD Card Connector
USB Hub IC
Downstream USB Port 0
Downstream USB Port 1
SD Reader
Upstream USB Port
Power Management
USB Cable to Head Unit (USB Host)
Vehicle Power
Vehicle Internal Wiring

Figure 3

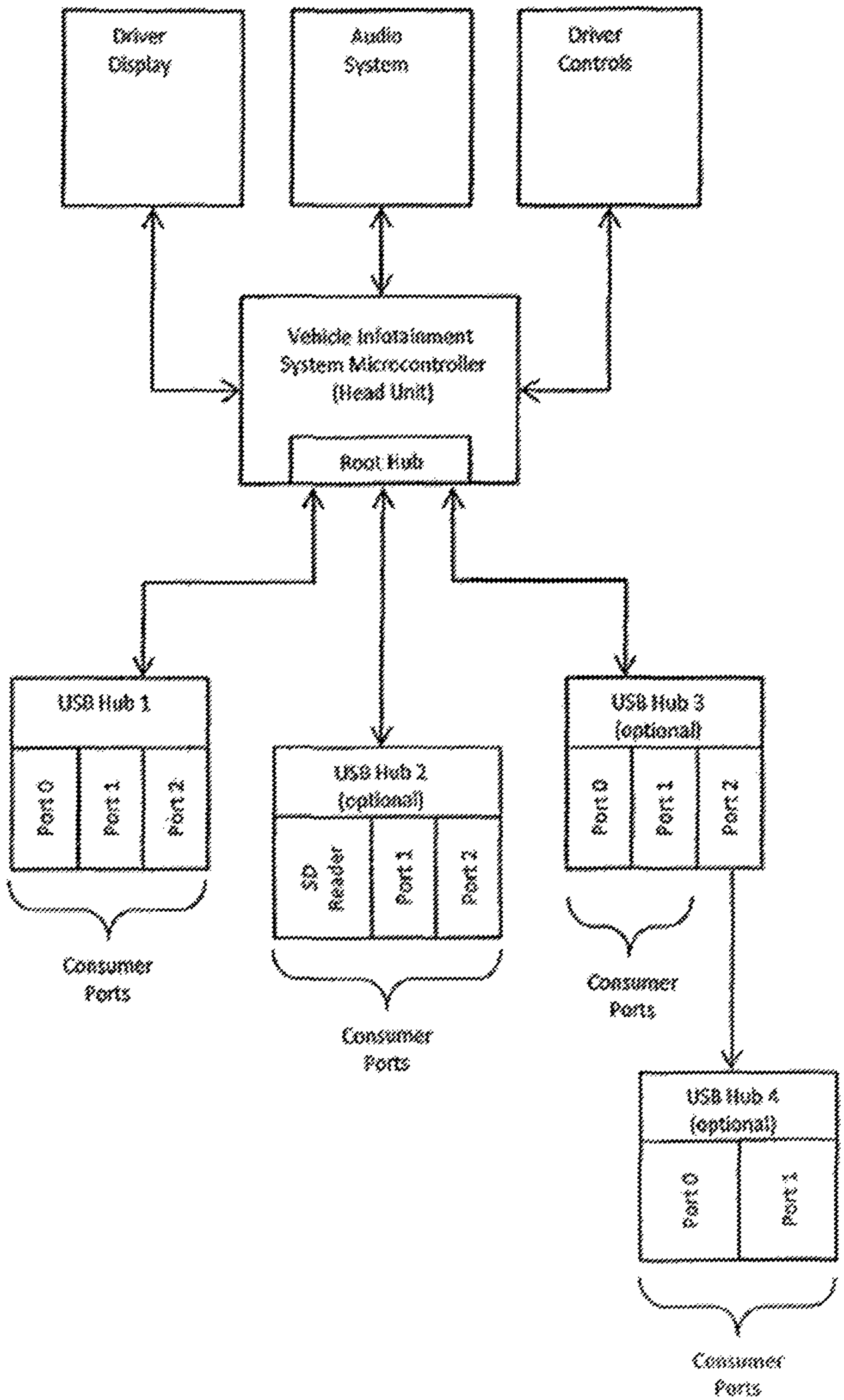

Driver Display
Audio System
Driver Controls
Vehicle Infotainment System Microcontroller (Head Unit)
Root Hub
USB Hub 1
Port 0
Port 1
Port 2
Consumer Ports
USB Hub 2 (optional)
SD Reader
Port 1
Port 2
Consumer Ports
USB Hub 3 (optional)
Port 0
Port 1
Port 2
Consumer Ports
USB Hub 4 (optional)
Port 0
Port 1
Consumer Ports

Figure 4

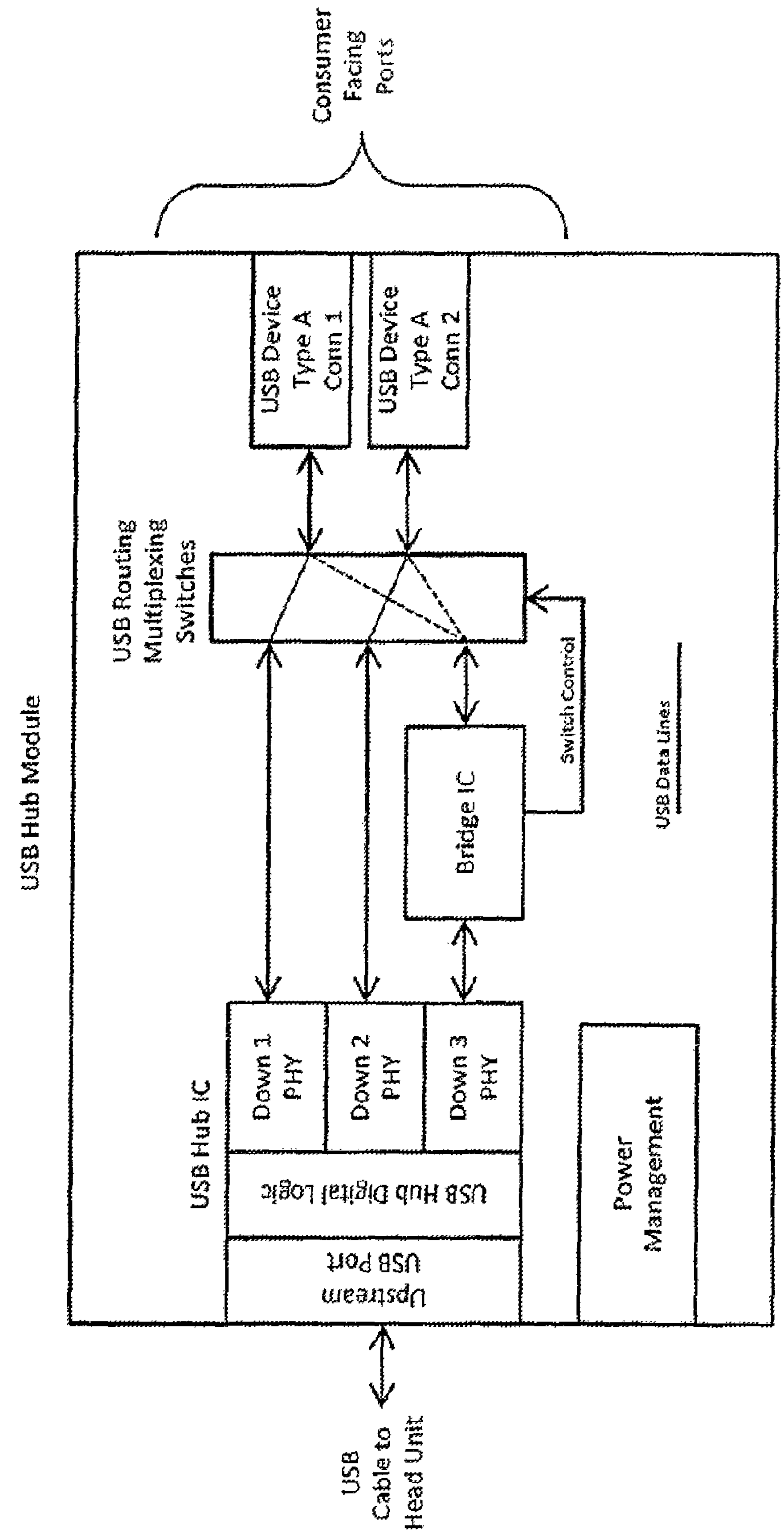

Consumer Facing Ports
USB Hub Module
USB Device Type A Conn 1
USB Device Type A Conn 2
USB Routing Multiplexing Switches
Switch Control
Bridge IC
USB Data Lines
USB Hub IC
Down 1 PHY
Down 2 PHY
Down 3 PHY
USB Hub Digital Logic
Upstream USB Port
Power Management
USB Cable to Head Unit

Figure 5

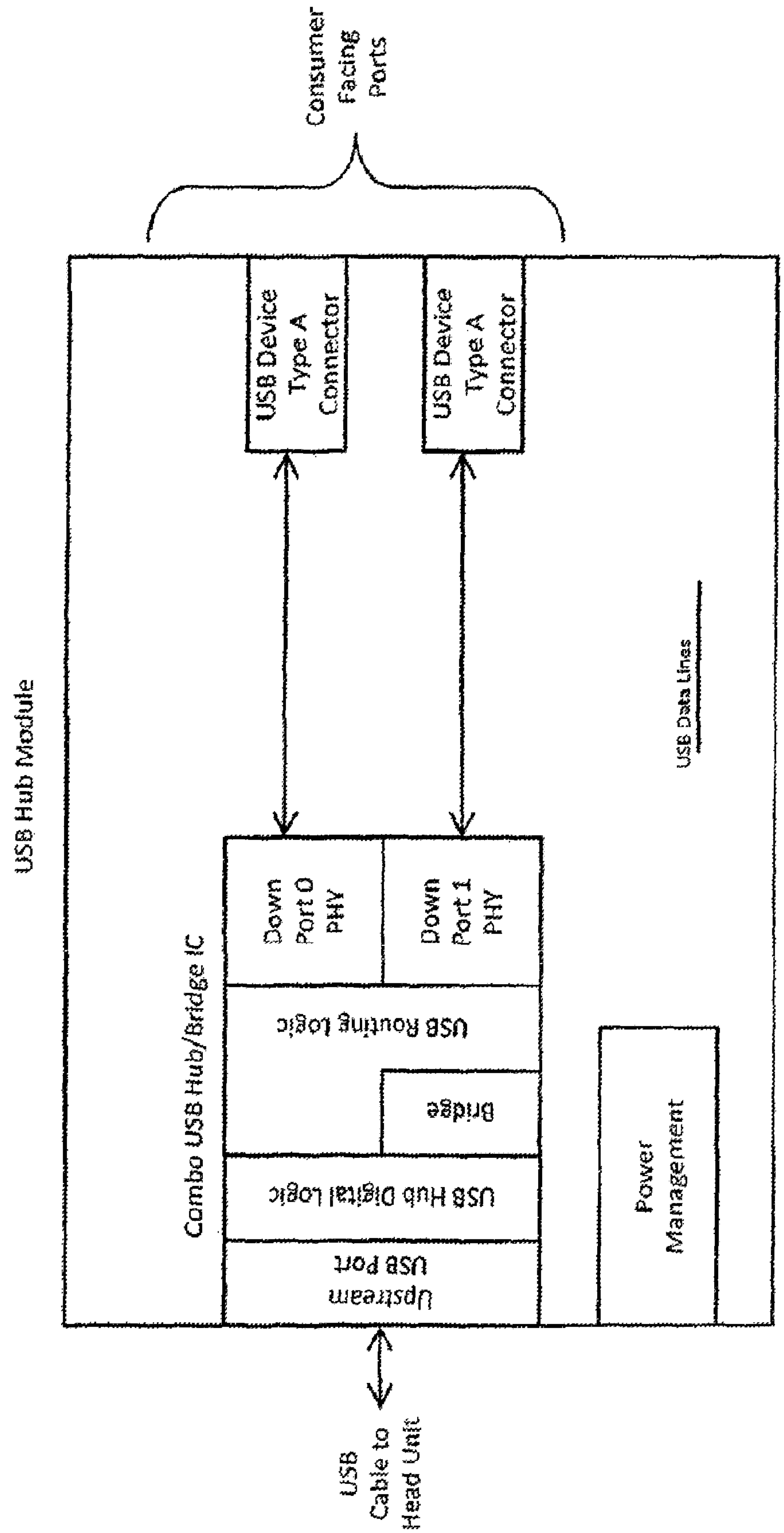

USB Hub Module
Consumer Facing Ports
USB Device Type A Connector
USB Device Type A Connector
USB Data Lines
Combo USB Hub/Bridge IC
Down Port 0 PHY
Down Port 1 PHY
USB Routing Logic
Bridge
USB Hub Digital Logic
Upstream USB Port
Power Management
USB Cable to Head Unit

Figure 6

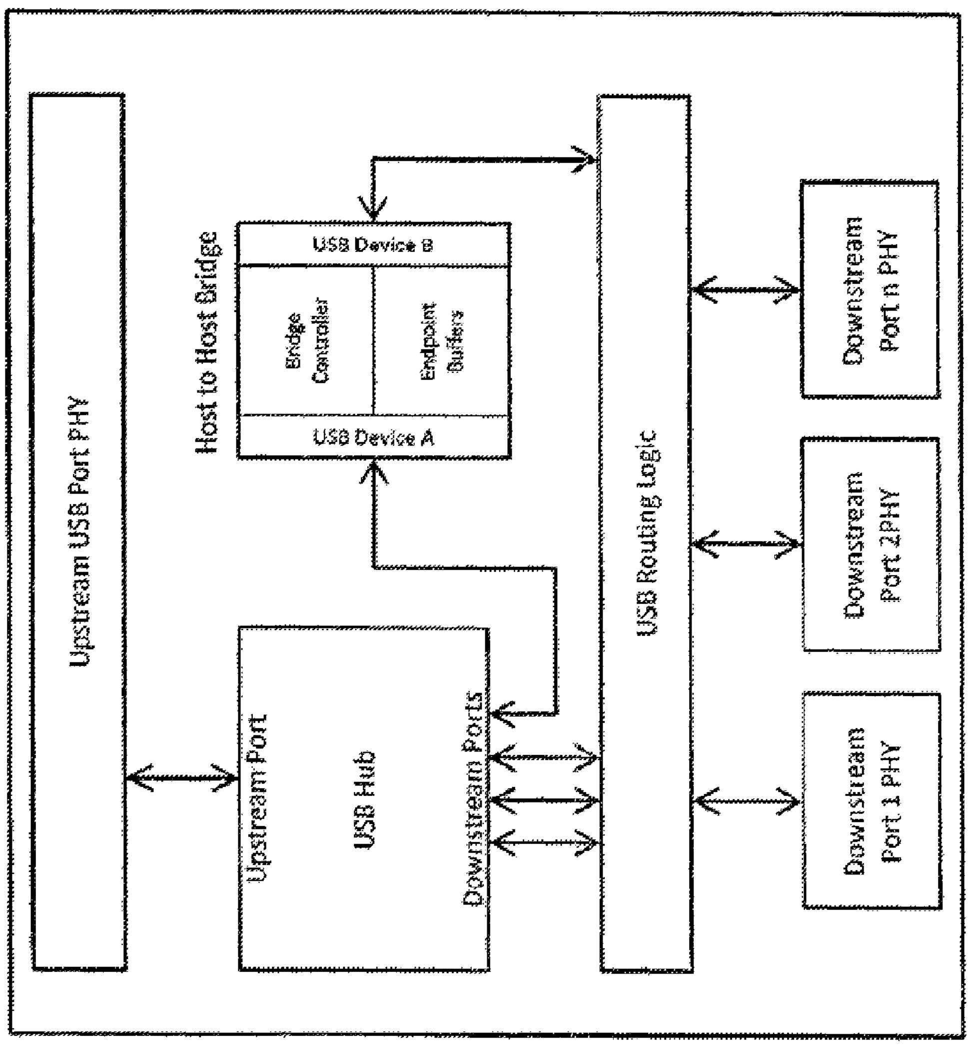

Upstream USB Port PHY
Host to Host Bridge
USB Device B
Bridge Controller
Endpoint Buffers
USB Device A
Upstream Port
USB Hub
Downstream Ports
USB Routing Logic
Downstream Port n PHY
Downstream Port 2PHY
Downstream Port 1 PHY

Figure 7

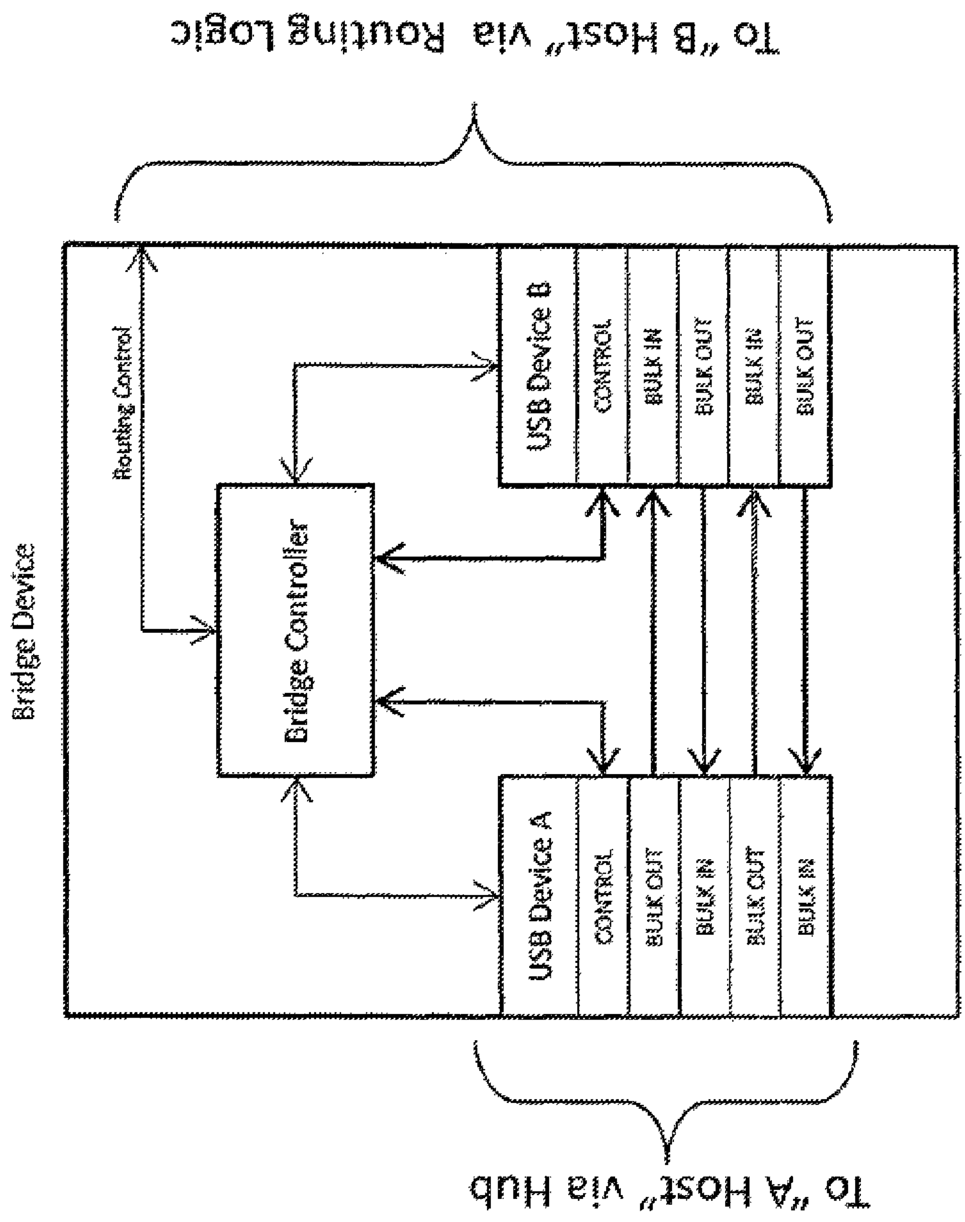
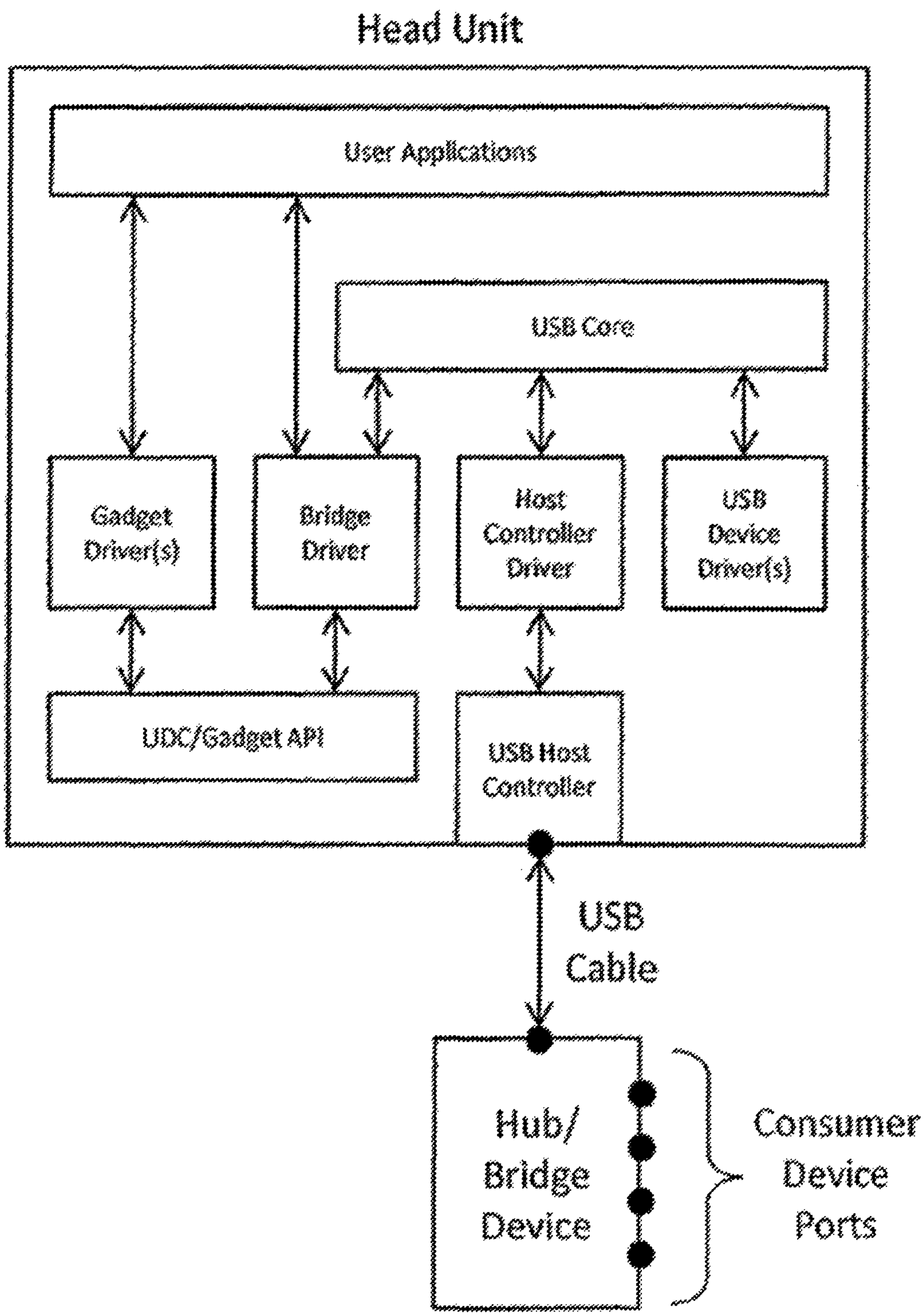

To "B Host" via Routing Logic
Bridge Device
Routing Control
Bridge Controller
USB Device B
CONTROL
BULK IN
BULK OUT
BULK IN
BULK OUT
USB Device A
CONTROL
BULK OUT
BULK IN
BULK OUT
BULK IN
To "A Host" via Hub

Figure 8


Head Unit
User Applications
USB Core
Gadget Driver(s)
Bridge Driver
Host Controller Driver
USB Device Driver(s)
UDC/Gadget API
USB Host Controller
USB Cable
Hub/ Bridge Device
Consumer Device Ports

FLEXIBLE MOBILE DEVICE CONNECTIVITY TO AUTOMOTIVE SYSTEMS WITH USB HUBS

RELATED APPLICATIONS

This application is a continuation application and claims benefit under 35 U.S.C. §120 of U.S. patent application Ser. No. 14/487,947, filed Sep. 16, 2014, which claimed benefit under 35 U.S.C. §119(e) of U.S. Provisional Patent Application No. 61/882,915, filed on Sep. 26, 2013, the entire disclosure of each of which are hereby incorporated herein by reference.

BACKGROUND

The present invention generally relates to Universal Serial Bus ("USB") connectivity between, for example, mobile consumer devices and vehicle electronic systems. More specifically, the present invention relates to a system which is configured to provide that consumer devices that act as either USB host or USB device can connect to a vehicle's embedded USB host that does not have On the Go ("OTG") capability through an embedded USB hub in the vehicle.

Historically, mobile consumer devices such as media players, smart phones, tablets and the like have relied on connections to other devices, such as laptop or desktop personal computers ("PC's") to acquire content, exchange data, and charge the device's internal battery. For many years now, that has been accomplished through USB ports on each device. The use of USB technology is suitable for such needs since it is commonly available, familiar to the end user, cost effective and ubiquitous. USB protocols require a point-to-point connection in which one end is the USB Host or master, and the other end is a USB Device or slave. In this way, the flow of messages between the two devices is managed and controlled, whereby the USB Device responds to messages initiated by the USB Host. Historically, PC's have provided USB Host ports for connection to simpler USB Devices such as printers, memory sticks, mobile phones, etc. The USB Host has a greater burden of software and hardware requirements than a USB Device, so it has made sense to designate the PC as the USB Host in such systems.

In vehicle systems that employ USB connections, the same concepts apply. In such systems, the vehicle is typically the USB Host. The USB Host function is often embedded into a component of the vehicle infotainment system, such as into the radio or other control module. Typically, multiple USB ports are strategically designed into the vehicle in locations convenient for the driver and passengers to connect their consumer devices. Once a consumer device is connected to one of the ports, the device begins charging and the vehicle infotainment system can access content on the consumer device. This is useful to enable features such as streaming music, video and other services the device may provide.

Such a system requires that each of the USB ports be physically connected to the vehicle's USB Host in a manner suitable for USB data flow. This is accomplished through electrical cabling which is embedded in the vehicle, and which connects each of the ports to the USB Host. Since there can be many USB ports in a vehicle, and each port requires a cable to connect the port to the USB Host, it is desirable to share cabling when possible to minimize cost and mass of the vehicle. This is accomplished through the use of USB Hubs. USB Hubs allow a single USB Host to

connect to multiple USB Devices over a single cable between the USB Host and the USB Hub. As shown in FIGS. **1** and **2**, a single USB Hub can connect one USB Host to several USB Devices. Specifically, FIG. **1** illustrates a system wherein a self-powered USB Hub having a plurality of USB ports connects to a plurality of USB Devices (via a plurality of consumer-facing USB ports), while FIG. **2** illustrates a system wherein a self-powered USB Hub provides not only a plurality of USB ports which are in communication with a plurality of consumer-facing USB ports, but also a Secure Digital ("SD") card reader which is connected to a consumer-facing SD card connector. Other portions of FIGS. **1** and **2**, such as Power Management, are standard in the industry and self-explanatory upon viewing FIGS. **1** and **2**.

Furthermore, as shown in FIG. **3**, multiple USB Hubs can be tiered, such that USB Hubs connect to other USB Hubs. Specifically, FIG. **3** illustrates a vehicle system architecture that includes a central vehicle microcontroller (also referred to as the Head Unit or "HU"). Connected to the Head Unit are components or systems such as displays, the audio system, entertainment system and the driver controls. The Head Unit may be architected as a single module encompassing all functions or distributed such that various functions are managed by individual modules. The Head Unit includes a Root USB Hub which is typically connected to one or more downstream USB Hubs distributed throughout the vehicle. Each USB Hub has a plurality of downstream ports (at least one of which may be an SD reader or USB audio device), thereby effectively providing that each USB port in the vehicle has a connection to the USB Host or Head Unit. In FIG. **3**, for example, the Root Hub is embedded in the radio, and is connected to four (4) self-powered USB Hubs, wherein one is in the vehicle's center console, one is in the vehicle's center stack, and two are in the vehicle's rear seats.

Recently, mobile devices such as smart phones have gained in popularity. This is, in part, due to their usefulness as standalone computing devices. With advances in consumer electronic technology and increases in the speed of mobile networks, these devices are no longer reliant on being connected to PCs to access content. These smart mobile devices now have many of the same hardware resources, connectivity and software operating systems that only PCs had in past years. As has been the case with desktop PCs, accessories for these mobile devices have become available to aid in their ease of use. These accessories have included devices such as keyboards, mice, displays, touchscreen, audio systems, and other interface devices. These accessories commonly connect via a USB connection. By way of established convention in the consumer electronics market, these accessories are typically low cost and limited in USB capability to act only as a USB Device. To connect them to a smart phone, the smart phone must be the USB Host. Therefore, leading mobile device manufacturers and system designers have begun designing their mobile device products (i.e. smart phones, tablets, etc.) to support both USB Host and USB Device roles. In other words, the phone may configure itself such that it can function as a USB Device when it needs to be, or as a USB Host when it needs to be. Recently, the system level design thinking has shifted towards viewing smart phones as the USB Host, and any device connecting thereto as the USB Device. Again, this is not surprising since this is exactly how laptops and PCs work today. Extending this trend into the future, it can be predicted that the smart phone will act

primarily as the USB Host, and will rarely or never act as a USB device. This presents some problems for automotive systems.

As explained previously, automotive systems have a USB Host and require USB Devices to connect to it. If a phone acts as a USB Host, then the system will not function since by USB convention, two USB Hosts cannot directly connect with each other. Automotive manufacturers desire compatibility with smart phones and are therefore motivated to adapt to this changing technology. A redesign of the USB architecture in the vehicle is thus necessary such that the vehicle can act either as the USB Host (when necessary to connect to USB Devices such as memory sticks, thumb drives, etc.) or USB Device (when necessary to connect to USB Hosts, such as a smart phone which demands to be USB Host rather than USB Device.

The USB organization has added a standard that addresses the need for devices to act as either USB Host or USB Device and as such can be considered a "dual role" USB controller. It is referred to in USB nomenclature as "On the Go" or "OTG" for short. Any device that meets the OTG standard can act as either USB Host or USB Device and can change roles dynamically. Therefore, one possible approach to modifying the vehicle USB architecture to support all use cases is to upgrade the vehicle's USB Host to USB OTG. This solution addresses the issue but has some disadvantages. First, USB Hubs do not support OTG and can no longer be used in the system. Each consumer accessible USB port that supports OTG must have a dedicated wire link to a dedicated OTG controller in the Head Unit thus negating the wiring savings associated with use of USB Hubs. As a result several costly cables may need to be added to the vehicle's electrical system. Second, there may not be enough OTG controllers available in the Head Unit to connect to each of the vehicle's user accessible USB ports. This then forces the vehicle designer to choose a limited number of the many USB ports in the vehicle to support the OTG function and run dedicated USB cables to them. This can lead to user confusion and dissatisfaction since only certain consumer ports support the required functionality. Also, ports that support OTG may be co-located with other physically identical ports that do not. If the user chooses the wrong one, the applications they desire to run from the consumer device that requires USB Host mode won't work.

Another possible solution is to implement custom USB hubs wherein the USB Hub is able to dynamically swap its upstream port with one it's downstream ports when commanded to do so. System solutions built with this concept still require OTG controllers in the head unit but benefit from the fact that no additional wires need to be installed in the car. The existing USB cable between the USB OTG Host and the USB Hub can facilitate the necessary USB communications between the USB OTG controller in the Head Unit (HU) and a consumer device in USB Host (such as a smart phone). This solution also has some disadvantages however. For example, when the USB Hub is commanded to swap its upstream port with a downstream port, all other downstream ports of the USB Hubs lose their data connection with the Head Unit. While in this mode the Head Unit access to the other downstream ports of the hub cease. This may prevent use of certain vehicle system functions such as navigation or audio playback that may need consistent access to the other downstream ports of the hub to function. Furthermore, it requires the HU to have an available USB OTG port and a signaling path to control the hub upstream/downstream port configuration.

SUMMARY

An object of an embodiment of the present invention is to provide a system which is configured to enable a vehicle's embedded USB Host system to connect to mobile devices through a USB Hub, regardless of whether the mobile devices are configured to act as USB Hosts or USB Devices, without the need to provide OTG or dual role controllers in the head unit and without the need to provide additional cabling in the vehicle. Preferably, no hardware changes are required to be made to the USB Host circuits in the HU.

An embodiment of the present invention provides a system which can be employed between a vehicle's embedded USB Host and at least one, but preferably multiple, consumer facing USB ports provided in the vehicle for connection to consumer devices. The system is configured to recognize and control whether the consumer device is required to be connected to each USB port as a USB Host or as a USB Device. Further, the system is able to dynamically switch the device connection between USB Device mode and USB Host mode when desired. In the case where the consumer device is acting as a USB Device, signals are routed normally through a USB Hub to the Head Unit. In the case where the consumer device is acting as a USB Host, signals between the consumer device and the vehicle's embedded USB Host are routed and processed through a USB Host to Host Bridge which is connected to the USB Hub, thereby rendering the consumer device compatible with the vehicle's embedded USB Host.

The present invention is capable of being implemented in several different embodiments. For example, an embodiment of the present invention comprises a USB Hub Module having a USB Hub, USB Bridge, and USB routing switches implemented as discrete devices. The USB Hub upstream port is configured to be connected to a vehicle's embedded USB Host (such as a USB Host in a Head Unit). The USB Hub Module also includes a switching device (such as USB analog multiplexing switches for example) that is configured to route each consumer port to either the Bridge or the Hub. The USB Bridge is configured to effectively control the switching device. The USB Bridge is configured, based on signals from the Head Unit, whether the consumer device which is connected to the USB port is acting as USB Host or USB Device. In the case where the consumer device is acting as USB Host, the USB Bridge controls the switching device to route the USB port to the Bridge. The Bridge processes the signals from the consumer device and provides them to the USB Hub, thereby rendering the consumer device compatible with the vehicle's embedded USB Host. In the case where the consumer device is acting as USB Device, the USB Bridge controls the switching device such that the switching device provides the signals to the USB Hub, effectively bypassing the Bridge.

Still another embodiment of the present invention provides that the USB routing logic, USB Bridge, and USB Hub are integrated in a single combination USB Hub/USB Bridge Integrated Circuit (IC).

Still other embodiments are entirely possible, some of which are described and illustrated herein. For example, the concept can be extended to include additional embedded USB Device functions such as USB HID and USB Audio. Further it is also envisioned that all consumer facing USB ports of the Hub Module can emulate or otherwise support dual role USB capability provided that each downstream port has a Bridge to support USB Host mode for the connected device and a direct connection to the USB Hub to

support USB Device mode. In all cases, compliance to USB protocols and architectures is preferably maintained.

BRIEF DESCRIPTION OF THE DRAWINGS

The organization and manner of the structure and operation of the invention, together with further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawings wherein like reference numerals identify like elements in which:

FIG. **1** illustrates a system wherein a multiple port self-powered USB Hub functions to connect a single USB Host to a plurality of USB ports;

FIG. **2** illustrates a system wherein a self-powered USB Hub provides not only a plurality of USB ports, but also a Secure Digital ("SD") card reader;

FIG. **3** illustrates a vehicle infotainment system structure wherein multiple USB Hubs are connected together or tiered, such that USB Hubs feed other USB Hubs;

FIG. **4** illustrates a system which is in accordance with an embodiment of the present invention, wherein a USB Hub, USB Bridge and a switching device are provided as discrete components;

FIG. **5** illustrates a system which is in accordance with an alternative embodiment of the present invention, wherein USB routing/switching logic and a USB Bridge are integrated with a USB Hub in a combination USB Hub/USB Bridge Integrated Circuit (IC);

FIG. **6** illustrates the different components of the combination USB Hub/Bridge IC shown in FIG. **5**;

FIG. **7** illustrates one possible endpoint configuration of the USB Bridge shown in FIGS. **5** and **6**; and

FIG. **8** illustrates an example implementation of a Head Unit Software Architecture.

DESCRIPTION OF ILLUSTRATED EMBODIMENTS

While this invention may be susceptible to embodiment in different forms, there are specific embodiments shown in the drawings and will be described herein in detail, with the understanding that the present disclosure is to be considered an exemplification of the principles of the invention, and is not intended to limit the invention to that as illustrated.

FIG. **4** illustrates a system which is in accordance with an embodiment of the present invention. The system is configured to effectively render a vehicle's embedded USB Host compatible with consumer devices which are configured to also act as USB Host or USB Device. The system is in the form of a self-powered USB Hub Module having a USB, a USB Bridge, and a switching device implemented as discrete devices. The USB Hub is preferably provided in the form of an integrated circuit (IC), and is configured (via an upstream USB port) connected to a vehicle's embedded USB Host (such as a USB Host in a Head Unit) via vehicle internal wiring, such as, in one embodiment, via a single USB data cable between the Head Unit and USB Hub. The USB Hub also includes a plurality of downstream USB ports, at least one of which is connected to a USB Bridge (which also is preferably provided in the form of an integrated circuit (IC)). At least one downstream USB port of the USB Hub is connected to a switching device (such as USB analog multiplexing switches, for example). The switching device is configured to be connected to at least one USB port in the vehicle for connection to a consumer device. The USB Bridge is configured to effectively control the

switching device although other control mechanisms are envisioned. The USB Hub Module is configured such that signals received from at least one USB port are received by the switching device, and the switching device routes the signals to the USB Bridge or the USB Hub. In the case where the consumer device is acting as USB Host, the USB Bridge processes the USB packets from the consumer port and provides them to the USB Hub, thereby rendering the consumer device compatible with the vehicle's embedded USB Host. In the case where the consumer device is acting as USB Device, the USB Bridge controls the switching device such that the switching device provides the USB signaling directly to the USB Hub, bypassing the Bridge.

As shown in FIG. **4**, the system also includes Power Management structure, as well as some other conventional structure not specifically shown in FIG. **4**, but which would be readily assumed to be present by one having ordinary skill in the art.

In use, the Head Unit controls the switching device via the USB Bridge hardware or any other convenient means of control. The HU software application may choose to enable, for example, a phone on any one of the consumer USB ports, by requesting, commanding or otherwise knowing the phone is required to be in USB Host mode and commanding the routing of the specific USB port the phone is attached to the USB Bridge. Once routed to the USB Bridge, the phone will detect a USB Device is connected and the phone will begin the standard USB enumeration sequence. The detection and enumeration processes are defined by USB standards and not explained here in detail. However, for purposes of describing the operation of the invention, a general understanding is provided herein. The enumeration process follows a strict sequence of USB descriptor requests from the USB Host and USB descriptor responses from the USB Device that allow the Host to determine the capabilities and functions of the Device and configure the USB Device for operation. Once the complete set of device descriptors are known the USB Host will then load the appropriate USB driver(s) and applications to support in the functionality that the USB Device provides. In the scope of this invention it is envisioned that the responses to the descriptor requests made by the phone (USB Host) are either answered locally by the Bridge or preferably, the requests are forwarded through the Bridge to the Head Unit where its device drivers process the request and return the response. The descriptor responses from the device driver are conveyed to the USB Bridge, which then, in turn, passes them to the phone. By passing descriptor request to the Head Unit drivers and returning the responses from the Head Unit drivers back to the consumer device, the Bridge appears as a transparent component in the USB system architecture. The system capabilities are controlled by the Head Unit and the system remains flexible without need for changes to the Bridge firmware or hardware when the system designer requires changes to the descriptor responses. Once the consumer device completes the enumeration process, the Head Unit's USB functional capabilities are known to the consumer device and the consumer device may enable use of those functions over USB communication. At this point, the consumer device or the Head Unit may begin activating any number of supported services such as data connections, streaming audio and streaming video to and from the vehicle via the USB Bridge.

Another embodiment of the present invention can be provided, wherein the bridge is configured to act as an OTG port thus negating the need for switches and/or routing logic. In this case there would exist one Bridge functional block for

each downstream port. This embodiment would effectively be a more generalized case of the example illustrated in FIG. **4**. FIG. **4** shows just one Bridge that any one of the consumer USB ports can be routed to. With just one bridge, only one consumer USB port can be connected to a USB host at a time. However, if each downstream port of the Hub has a dedicated Bridge, then multiple consumer ports can support connection to USB Host devices at the same time. Thus, any consumer port can be in either USB Host or USB Device mode at any time independently of the others.

FIG. **5** illustrates an alternative embodiment wherein the switching device comprises USB routing logic, and both the USB routing logic and the USB Bridge are integrated with the USB Hub in a combination USB Hub/USB Bridge Integrated Circuit (IC). This configuration has cost and size advantages over building it with discrete components connected together on a printed circuit board.

FIG. **6** illustrates the internal components of the USB Hub/USB Bridge Integrated Circuit (IC) shown in FIG. **5**. As shown, preferably the components of the USB Bridge include a bridge controller as well as endpoint buffers. While the exact configuration of endpoints is effectively up to the system designer to choose for a particular need, a specific example of one possible endpoint configuration is shown in FIG. **7**; however, many others are possible.

As shown in FIG. **7**, the endpoints of the Bridge may be designed to support multiple pipes of Bulk USB data connections between the Host A (Head Unit) and Host B (consumer device). In the Bridge, the IN endpoints of Device A are connected to the OUT endpoints of Device B and the OUT endpoints of Device A are connected to the IN endpoints of Device B. The design of the Bridge may be such that the data flow between the endpoints may be direct or buffered. For example, in the case of direct connection, once a USB packet is received from Host A on a Device A OUT endpoint, the internal logic of the Bridge moves to packet to the Device B IN endpoint if it is available. If Device B IN endpoint is full or otherwise not available then subsequent attempts of Host A to send more packets to Device A in the Bridge will be rejected until such time that the Device B IN endpoint is clear and the contents of the Device A OUT buffer is moved to it. Alternatively, there may exist a local buffer in the Bridge between the endpoints of Device A and B. For example, packets received on an OUT endpoint of Device A are placed in a local memory device for temporary storage until Device B IN endpoint is ready for them. The OUT endpoints are thus capable of receiving multiple packets from the Host until the buffer is full. Likewise the IN endpoints may, at times, transmit multiple packets until the buffer is empty. Such buffers are not required, but are envisioned, to improve system throughput performance in certain circumstances where one of the USB Hosts is occasionally busy and not keeping up with USB transactions at the same rate as the other USB Host. Regardless of the buffer configuration, the Bridge hardware has IN and OUT endpoints on Device A mapped to OUT and IN endpoints respectively on Device B, thus forming a bidirectional bridge that passes USB traffic between two USB Hosts with bandwidth sufficient to support the application requirements of the system.

Also shown in FIG. **7**, Device A and Device B provide a bidirectional Control endpoint connected to their respective USB Hosts. Control endpoints are required per USB standard to support USB defined control messages between the Host and Device both during and after the enumeration sequence. Optionally, USB endpoints may also be utilized per USB standard to employ messages intended to control user defined custom device specific behavior, referred to as Vendor Specific messages. As can be seen in FIG. **7**, the Control endpoints are mapped to the Bridge Controller (BC). The BC logic may be implemented in hardware or preferably software. The BC provides the capability to send, receive and process USB standard Control endpoint messages as well as vendor specific messages essential to the control and operation of the Bridge. At system startup, the A Host requests and receives descriptors from the BC via the Control endpoint. Once complete, Host A then loads the Bridge Driver in its software stack and configures the custom Bridge hardware for operation. Host A can then control the functions of the Bridge, such as USB switch routing control. The system is now ready to accept connection with USB Host mode consumer devices on the B Device of the Bridge. When such a connection is made, the BC will notify the Bridge Driver in Host A by sending a message on the control endpoint to Host A. Further, Host B will begin sending descriptor requests on the control endpoint to Device B in Bridge. The BC receives theses requests, encapsulates them with information that identifies them as descriptor requests from Host B and passes them to the Bridge Driver on Host using the control endpoint. Host A Bridge Driver receives these requests, identifies them as descriptor requests and passes the requests on to other software components in Host A system and waits for the descriptor responses. The descriptor responses are encapsulated by the Bridge driver to indicate they are descriptor responses that are to be forwarded to Host B. The response is then sent to the BC via the control endpoint. The BC receives them, identifies them as descriptor responses that should be forwarded to Device B and places them on the control endpoint for Device B. This process of receiving and forwarding messages back and forth between the two hosts continues until the enumeration process is complete with Host B. From that point on the two hosts may begin to use the IN and OUT endpoints to transfer application data and services over the bulk endpoints.

FIG. **8** illustrates one possible configuration of the system architecture including software components in the Head Unit interfacing with the Bridge/Hub. There are multiple ways that the operating system and software architecture can be constructed to support the functions of the USB Bridge/Hub. In FIG. **8**, a typical Linux implementation is shown including the Bridge/Hub Module and the Head Unit. The system design utilizes standard Linux Kernel components and configurations and should be familiar to those skilled in the art. The Head Unit USB Host Controller hardware is driven by the Host Controller Driver. The Host Controller Driver is connected to the USB Core. The USB Core connects the HCD with the standard USB Linux Device Drivers and the custom Bridge Driver. The Bridge Driver is configured to optionally connect directly to the User Space Application software or to the USB Gadget Driver depending on system architecture. The custom Bridge Driver plays a dual role of both controlling the functions of the Bridge hardware as well as providing a data path between the gadget device drivers and applications running on the Head Unit. The architecture illustrated is capable of handling both the operation and data paths associated with the Bridge and the Hub at the same time, thus allowing concurrent operation of consumer devices operating in USB Device mode with consumer devices operating in USB Host mode. In one embodiment, the Hub/Bridge supports simultaneous active USB data connections between the Head Unit and multiple consumer devices, at least one of which being in host mode while the others are in device mode. In another embodiment,

the Hub/Bridge supports simultaneous active USB data connections between the Head Unit and some combination of embedded and consumer USB devices along with at least one device being in host mode. While it is understood that the software functions of the head unit are essential to building a complete system, the designs of which can vary significantly and this example is provided only as a means of demonstrating one way to utilize the functionality of the present invention.

What is claimed is:

1. A Universal Serial Bus (USB) hub module, comprising:

a first USB port configured to be connected to a USB host;

a second USB port configured to be connected to a consumer device;

a USB hub interconnected to the first USB port and the second USB port;

a USB bridge interconnected to the USB hub; and

a USB routing switch interconnected to the USB bridge, the USB hub, and the second USB port, wherein the USB routing switch is configured to connect the second USB port to the first USB port through the USB bridge, thereby providing bidirectional initiation of communication between the USB host and the consumer device when the consumer device connected to the second USB port is in a USB host mode and wherein the USB routing switch is configured to connect the second USB port directly to the first USB port through the USB hub, thereby only responding to communication initiated by the USB Host when the consumer device connected to the second USB port is in a USB device mode.

2. The USB hub module according to claim **1**, wherein the USB routing switch is configured to connect the second USB port to the first USB port through the USB bridge thereby providing bidirectional initiation of communication between the USB host and the consumer device when the consumer device connected to the second USB port is in the USB host mode and wherein the USB routing switch is configured to simultaneously connect another second USB port directly to the first USB port through the USB hub, thereby only responding to communication initiated by the USB Host when another consumer device connected to the another second USB port is in the USB device mode.

3. The USB hub module according to claim **1**, wherein the USB hub module is configured to recognize whether the consumer device connected to the second USB port is in the USB host mode or in the USB device mode and control the USB routing switch accordingly.

4. The USB hub module according to claim **1**, wherein the USB hub module is configured to dynamically switch operation of the second USB port between supporting the consumer device in the USB device mode or the USB host mode.

5. The USB hub module according to claim **1**, wherein the USB routing switch is configured to connect the consumer device to either the USB bridge or the USB hub based on whether the consumer device attached to the second USB port is configured to act as the USB host or a USB device.

6. The USB hub module according to claim **1**, wherein the USB bridge is configured to control the USB routing switch.

7. An integrated circuit, comprising:

a USB hub configured to be interconnected to a first USB port connected to a USB host and a second USB port connected to a consumer device;

a USB bridge interconnected to the USB hub; and

a USB routing switch interconnected to the USB bridge, the USB hub, and the second USB port, wherein the USB routing switch is configured to connect the second USB port to the first USB port through the USB bridge thereby providing bidirectional initiation of communication between the USB host and the consumer device when the consumer device connected to the second USB port is in a USB host mode and wherein the USB routing switch is configured to connect the second USB port directly to the first USB port through the USB hub, thereby only responding to communication initiated by the USB Host when the consumer device connected to the second USB port is in a USB device mode.

8. The integrated circuit according to claim **7**, wherein the USB routing switch is configured to connect the second USB port to the first USB port through the USB bridge thereby providing bidirectional initiation of communication between the USB host and the consumer device when the consumer device connected to the second USB port is in the USB host mode and wherein the USB routing switch is configured to simultaneously connect another second USB port directly to the first USB port through the USB hub, thereby only responding to communication initiated by the USB Host when another consumer device connected to the another second USB port is in the USB device mode.

9. The integrated circuit according to claim **7**, wherein the integrated circuit is configured to recognize whether the consumer device connected to the second USB port is in the USB host mode or in the USB device mode and control the USB routing switch accordingly.

10. The integrated circuit according to claim **7**, wherein the integrated circuit is configured to dynamically switch operation of the second USB port between supporting the consumer device in the USB device mode or the USB host mode.

11. The integrated circuit according to claim **7**, wherein the USB routing switch is configured to connect the consumer device to either the USB bridge or the USB hub based on whether the consumer device attached to the second USB port is configured to act as the USB host or a USB device.

12. The integrated circuit according to claim **7**, wherein the USB bridge is configured to control the USB routing switch.

13. A method of operating a USB hub module having a USB hub configured to be interconnected to a first USB port connected to a USB host and a second USB port connected to a consumer device, a USB bridge interconnected to the USB hub, and a USB routing switch interconnected to the USB bridge, the USB hub, and the second USB port, said method comprising the steps of:

determining when the consumer device is operating in a USB host mode and in a USB device mode;

connecting the consumer device via the second USB port to the USB hub via the first USB port through the USB routing switch and the USB bridge, thereby providing bidirectional initiation of communication between the USB host and the consumer device when the consumer device is determined to be in the USB host mode; and

connecting the consumer device via the second USB port to the USB hub via the first USB port through the USB routing switch and the USB hub thereby bypassing the USB bridge to only respond to communication initiated by the USB host when the consumer device is determined to be in the USB device mode.

14. The method according to claim **13**, wherein the step of determining if when the consumer device is operating in the USB host mode or in the USB device mode is performed by the USB routing switch.

15. A Universal Serial Bus (USB) connectivity module, comprising:

a first USB port;

a second USB port;

a USB host-to-host bridge connected to said first USB port;

a USB routing switch connected to said first USB port, said second USB port and said USB host-to-host bridge, wherein said USB routing switch is configured to provide a communication link between said first USB port and said second USB port through said USB host-to-host bridge, thereby providing bidirectional initiation of communication between the USB host and the consumer device when a first consumer device connected to said second USB port is operating in a USB host mode and wherein said USB routing switch is configured to provide another communication link between said first USB port and said second USB port that bypasses said USB host-to-host bridge, thereby only responding to communication initiated by the USB host when the first consumer device connected to said second USB port is operating in a USB device mode.

16. The USB connectivity module according to claim **15**, further comprising a third USB port, wherein said USB routing switch is configured to provide a first communication link between said first USB port and said second USB port through said host host-to-host bridge, thereby providing bidirectional initiation of communication between the USB host and the consumer device when the first consumer device connected to said second USB port is operating in the USB host mode and wherein said USB routing switch is configured to provide simultaneously provide a second communication link between said first USB port and said third USB port that bypasses said USB host-to-host bridge, thereby only responding to communication initiated by the USB Host when a second consumer device connected to said third USB port is operating in the USB device mode.

17. The USB connectivity module according to claim **15**, further comprising a third USB port, wherein said USB routing switch is further connected to the third USB port, wherein said USB routing switch is configured to provide a first communication link between said first USB port and said second USB port through said USB host-to-host bridge, thereby providing bidirectional initiation of communication between the USB host and the consumer device when the first consumer device connected to said second USB port is operating in the USB host mode, and wherein said USB routing switch is configured to provide a second communication link between said first USB port and said third USB port that bypasses said USB host-to-host bridge, thereby only responding to communication initiated by the USB host when a second consumer device connected to said third USB port is operating in the USB device mode without interrupting the first communication link between said first USB port and said second USB port.

18. A communication system, comprising:

a USB hub including a first USB port and a second USB port;

a central vehicle microcontroller connected to said first USB port;

a first consumer device connected to said second USB port;

a USB host-to-host bridge connected to said first USB port;

a USB routing switch providing a first communication path between said second USB port and said USB host-to-host bridge and a second communication path between said second USB port and said first USB port that bypasses said USB host-to-host bridge, wherein said USB routing switch connects said first communication path when the first consumer device is connected to said second USB port and is operating in a USB host mode, thereby providing bidirectional initiation of communication between the USB host and the consumer device and wherein said USB routing switch connects said second communication path, thereby only responding to communication initiated by the USB host when the first consumer device is connected to said second USB port and is operating in a USB device mode.

19. The communication system according to claim **18**, further comprising a second consumer device, wherein the USB hub includes a third USB port and wherein the USB routing switch further connects a third communication path between said third USB port and said first USB port that bypasses said USB host-to-host bridge, thereby only responding to communication initiated by the USB Host when the second consumer device is connected to said third USB port and is operating in the USB device mode.

20. The communication system according to claim **19**, wherein said USB routing switch is configured to simultaneously provide the second communication path between said first USB port and said third USB port without interrupting the first communication path between said first USB port and said second USB port.

* * * * *

EXHIBIT B

US009645962B2

(12) **United States Patent**
Voto et al.

(10) **Patent No.: US 9,645,962 B2**
(45) **Date of Patent: *May 9, 2017**

(54) **FLEXIBLE MOBILE DEVICE CONNECTIVITY TO AUTOMOTIVE SYSTEMS WITH USB HUBS**

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(73) Assignee: **Delphi Technologies, Inc.**, Troy, MI (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **15/257,096**

(22) Filed: **Sep. 6, 2016**

(65) **Prior Publication Data**

US 2016/0371213 A1 Dec. 22, 2016

Related U.S. Application Data

(63) Continuation-in-part of application No. 14/487,947, filed on Sep. 16, 2014, now Pat. No. 9,460,037.
(Continued)

(51) **Int. Cl.**
G06F 13/36 (2006.01)
G06F 13/40 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***G06F 13/4022*** (2013.01); ***G06F 13/385*** (2013.01); ***G06F 13/4045*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC G06F 13/4022; G06F 13/4045; G06F 13/385; G06F 13/387; G06F 13/366; G06F 13/4068; G06F 13/4282; G06F 13/4027
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,073,188 A 6/2000 Fleming
6,732,219 B1 5/2004 Broyles
(Continued)

FOREIGN PATENT DOCUMENTS

JP 2003256351 A 9/2003
TW 470887 B 1/2002

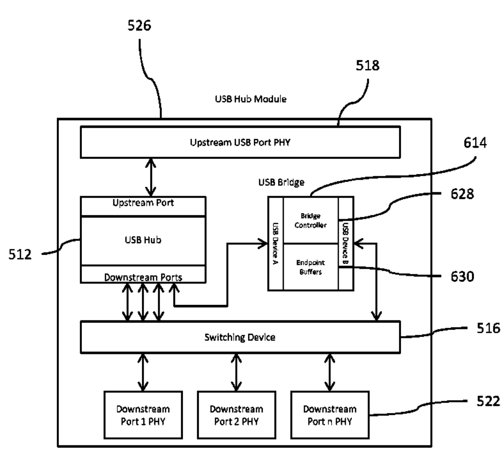
OTHER PUBLICATIONS

"FFI Rapport—A Study of Computer Interfaces for Soldier Systems", Lars Erik Olsen & Joakin Flathagen, Norwegian Defence Research Establishment, Oct. 10, 2005.
(Continued)

Primary Examiner — Ernest Unelus
(74) *Attorney, Agent, or Firm* — Robert J. Myers

(57) **ABSTRACT**

A USB hub module which is configured to enable a vehicle's embedded USB host to connect to multiple mobile devices through a USB hub, regardless of whether the mobile devices are configured to act as USB hosts or USB devices, without providing USB OTG controllers or additional vehicle wiring or inhibiting functionality of consumer devices connected the module while one consumer device connected to the module operates in USB host mode. Preferably, the module is configured so that no additional cabling or hardware changes are required to the head unit. The module can be employed between the embedded USB host, USB hub and at least one consumer accessible USB port. When the consumer device is acting as a USB host, signals between the consumer device and the vehicle's
(Continued)



embedded USB host are processed through a bridge, thereby rendering the consumer device compatible with the embedded USB host.

19 Claims, 10 Drawing Sheets

Related U.S. Application Data

(60) Provisional application No. 61/882,915, filed on Sep. 26, 2013.

(51) **Int. Cl.**
G06F 13/42 (2006.01)
G06F 13/38 (2006.01)

(52) **U.S. Cl.**
CPC .. ***G06F 13/4282*** (2013.01); *G06F 2213/0042* (2013.01); *G06F 2213/4004* (2013.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,934,793 B2	8/2005	Ying et al.	
6,957,287 B2	10/2005	Lou et al.	
7,130,656 B2	10/2006	Okagaki et al.	
7,280,802 B2	10/2007	Grady	
7,478,191 B2	1/2009	Wurzburg et al.	
7,523,243 B2	4/2009	Bohm et al.	
7,627,708 B2	12/2009	Bohm et al.	
8,447,598 B2	5/2013	Chutorash et al.	
8,447,890 B1	5/2013	LeTourneur et al.	
2003/0167345 A1	9/2003	Knight et al.	
2006/0056401 A1	3/2006	Bohm et al.	
2007/0067553 A1	3/2007	Chang	
2007/0086724 A1	4/2007	Grady et al.	
2007/0156293 A1	7/2007	Kellzi et al.	
2008/0005262 A1	1/2008	Wurzburg et al.	
2009/0117890 A1	5/2009	Jacobsen et al.	
2011/0054721 A1	3/2011	Goodrich et al.	
2011/0124300 A1	5/2011	Sinai	
2011/0208891 A1*	8/2011	Meyers	G06F 13/385 710/313
2011/0208892 A1*	8/2011	Meyers	G06F 13/4226 710/313
2012/0134506 A1	5/2012	DeBiasio et al.	
2012/0191811 A1	7/2012	Ng et al.	
2012/0290859 A1	11/2012	Saladin et al.	
2013/0053003 A1	2/2013	King, II	
2013/0106750 A1	5/2013	Kurosawa	
2016/0132448 A1*	5/2016	Maung	G06F 13/366 710/104

OTHER PUBLICATIONS

"USB 2.0 Autoswitch User's Manual", Lindy Electronics Limited & Lindy-Elektronic GMBH, Sep. 2002.

"APC USB 2.0 Host Controller—Device Driver Download", http://www.liutilities.com/devicedriver/apcusb20hostcontroller/, Jul. 2002.

"Peripheral-Sharing Hardware Suits Education's Needs to a 'T'", Terian Tyre, T H E Journal (Technological Horizons In Education), Oct. 1988.

* cited by examiner

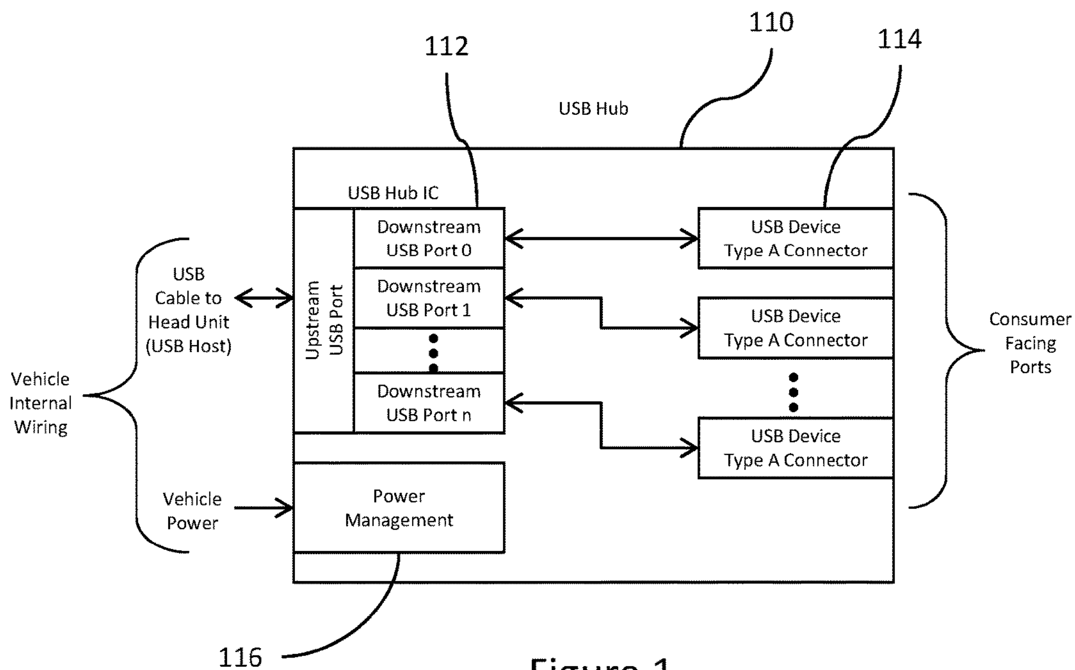


Figure 1

PRIOR ART

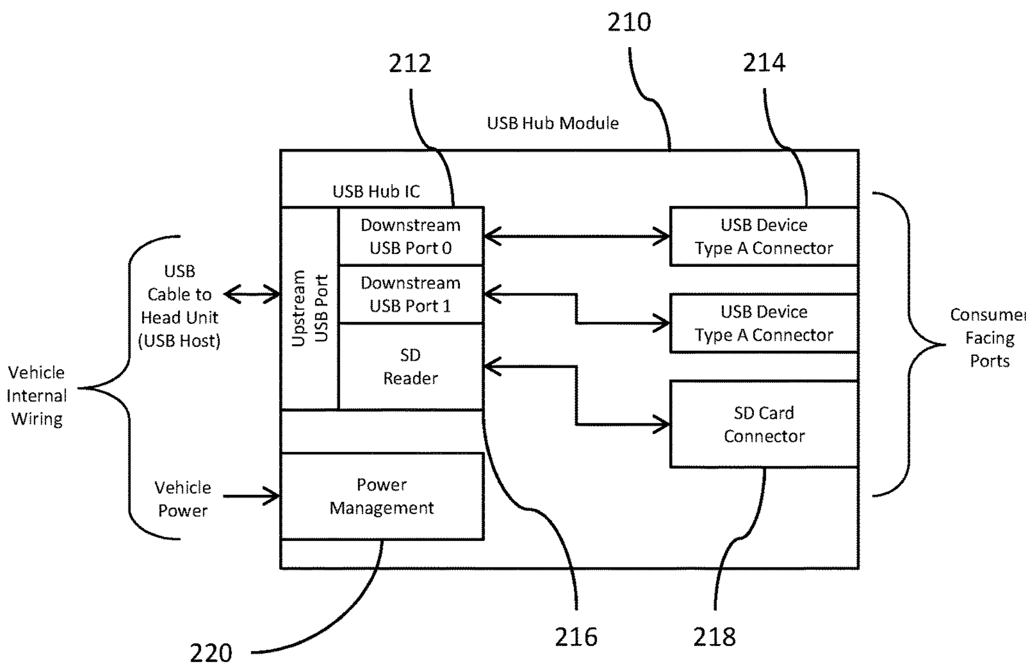


Figure 2

PRIOR ART

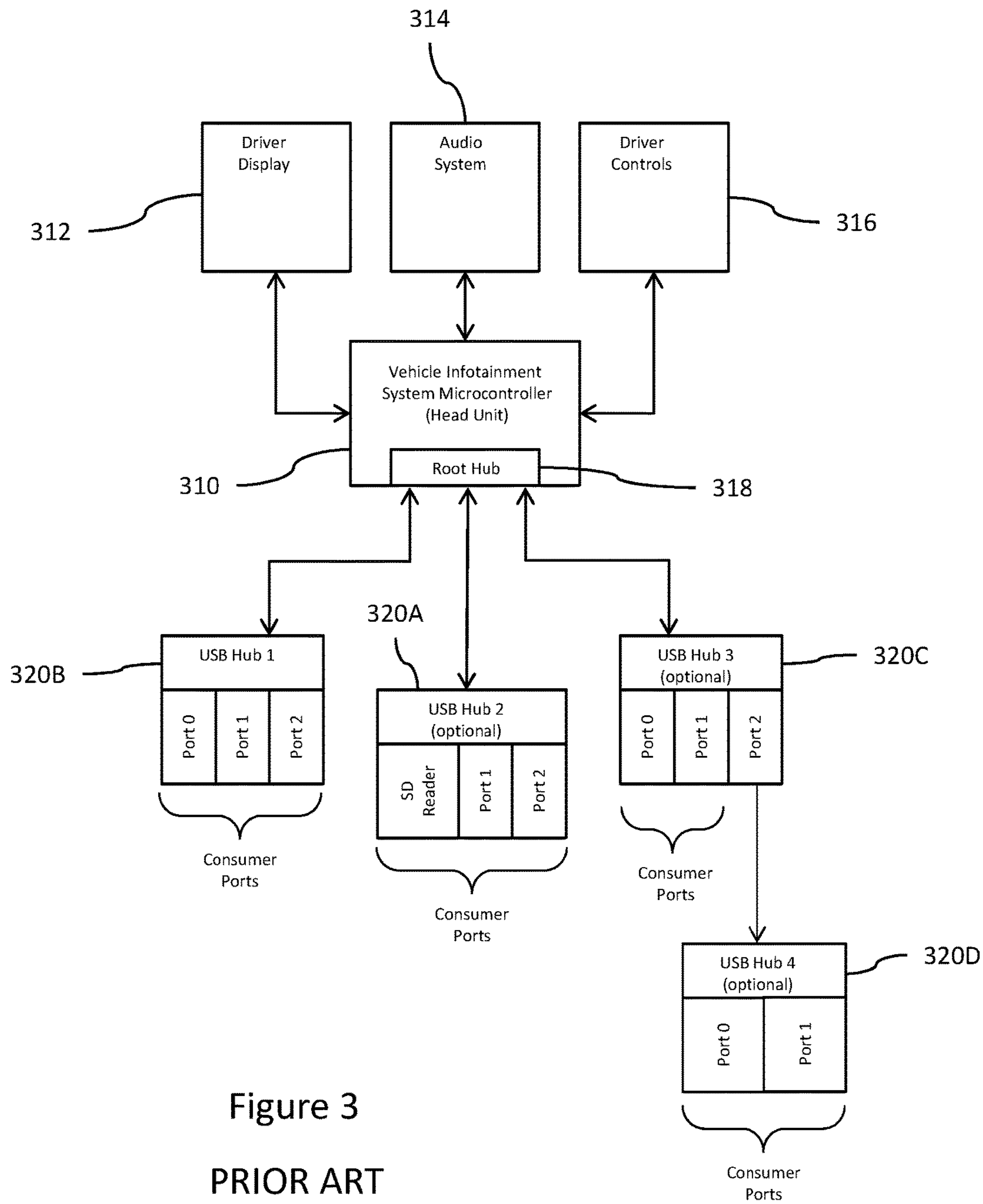


Figure 3

PRIOR ART

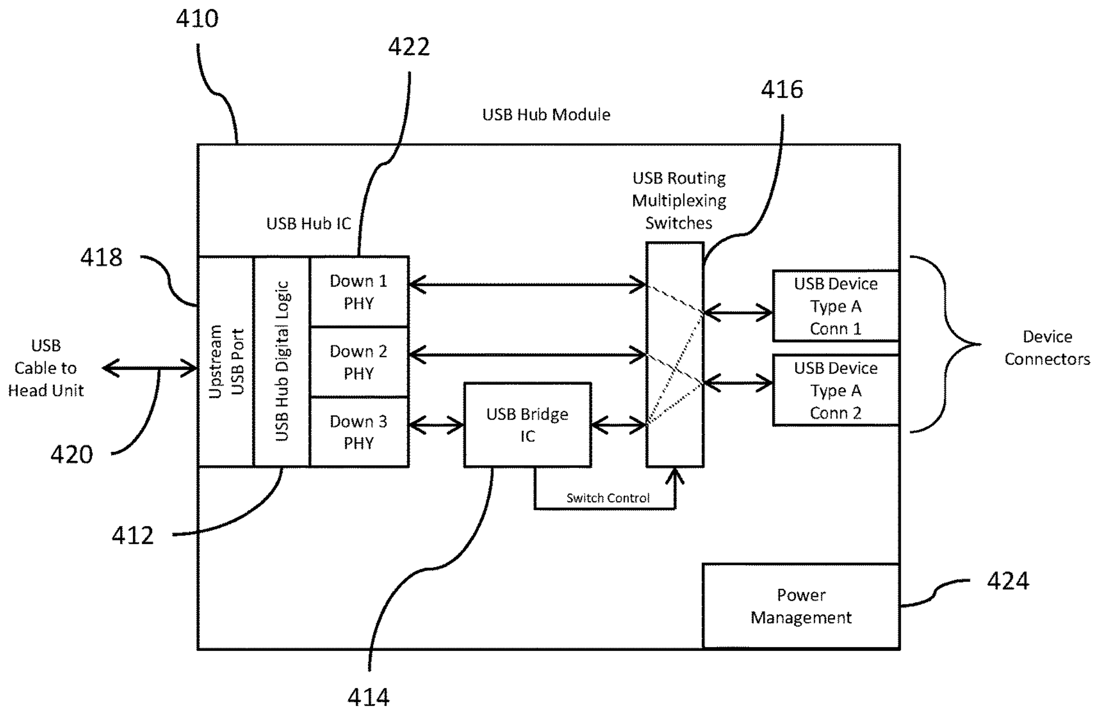

410
422
416
USB Hub Module
USB Hub IC
USB Routing Multiplexing Switches
418
Upstream USB Port
USB Hub Digital Logic
Down 1 PHY
Down 2 PHY
Down 3 PHY
USB Cable to Head Unit
420
USB Bridge IC
USB Device Type A Conn 1
USB Device Type A Conn 2
Device Connectors
Switch Control
412
Power Management
424
414

Figure 4

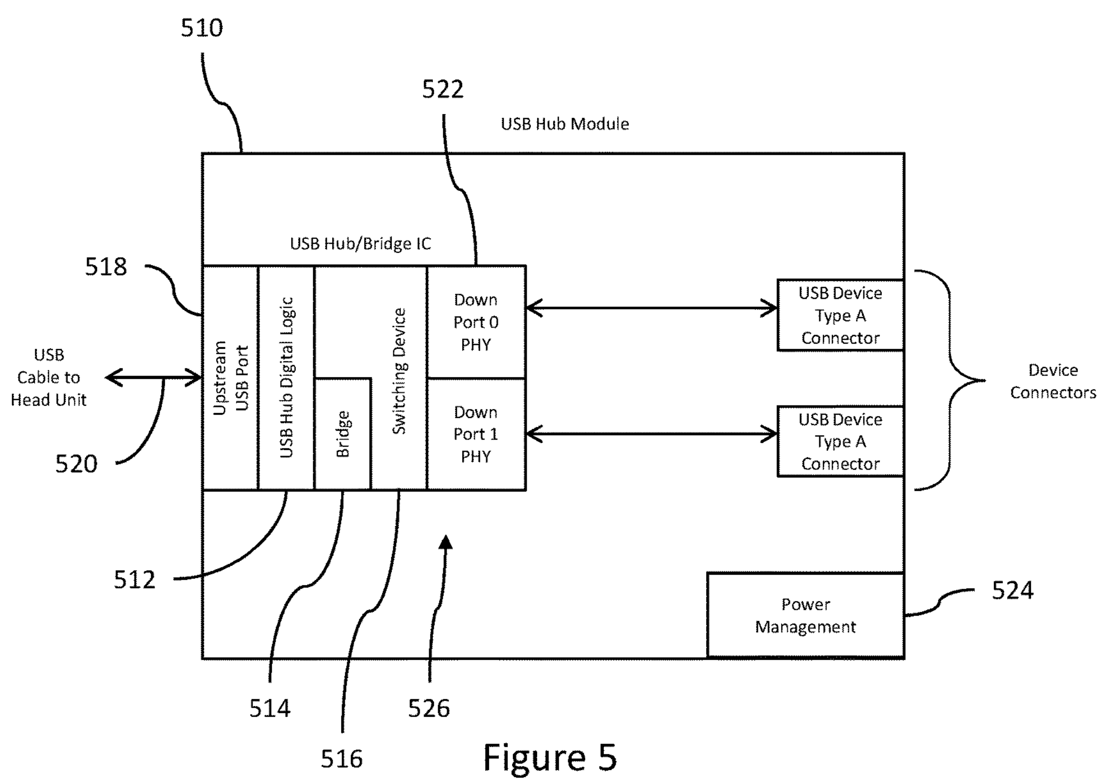

510
522
USB Hub Module
USB Hub/Bridge IC
518
USB
Cable to
Head Unit
520
Upstream
USB Port
USB Hub Digital Logic
Bridge
Switching Device
Down
Port 0
PHY
Down
Port 1
PHY
USB Device
Type A
Connector
USB Device
Type A
Connector
Device
Connectors
Power
Management
524
512
514
516
526

Figure 5

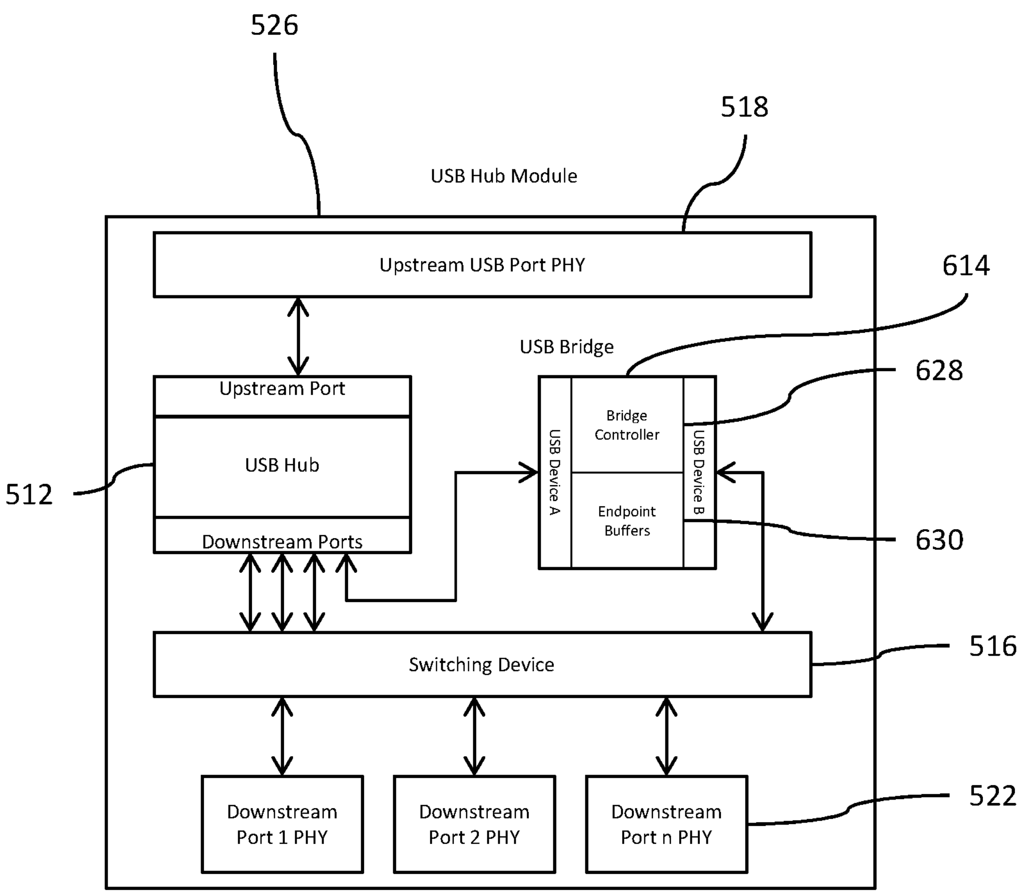
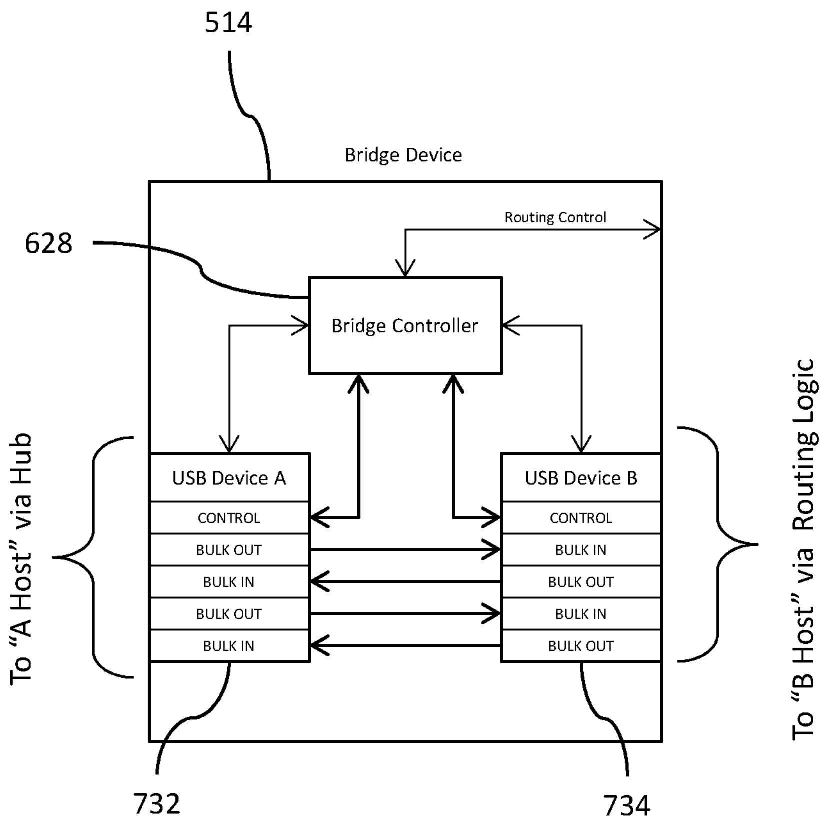

526
518
USB Hub Module
Upstream USB Port PHY
614
USB Bridge
628
Upstream Port
USB Hub
Downstream Ports
512
Bridge Controller
Endpoint Buffers
USB Device A
USB Device B
630
Switching Device
516
Downstream Port 1 PHY
Downstream Port 2 PHY
Downstream Port n PHY
522

Figure 6



514
Bridge Device
628
Routing Control
Bridge Controller
To "A Host" via Hub
USB Device A
CONTROL
BULK OUT
BULK IN
BULK OUT
BULK IN
USB Device B
CONTROL
BULK IN
BULK OUT
BULK IN
BULK OUT
To "B Host" via Routing Logic
732
734

Figure 7

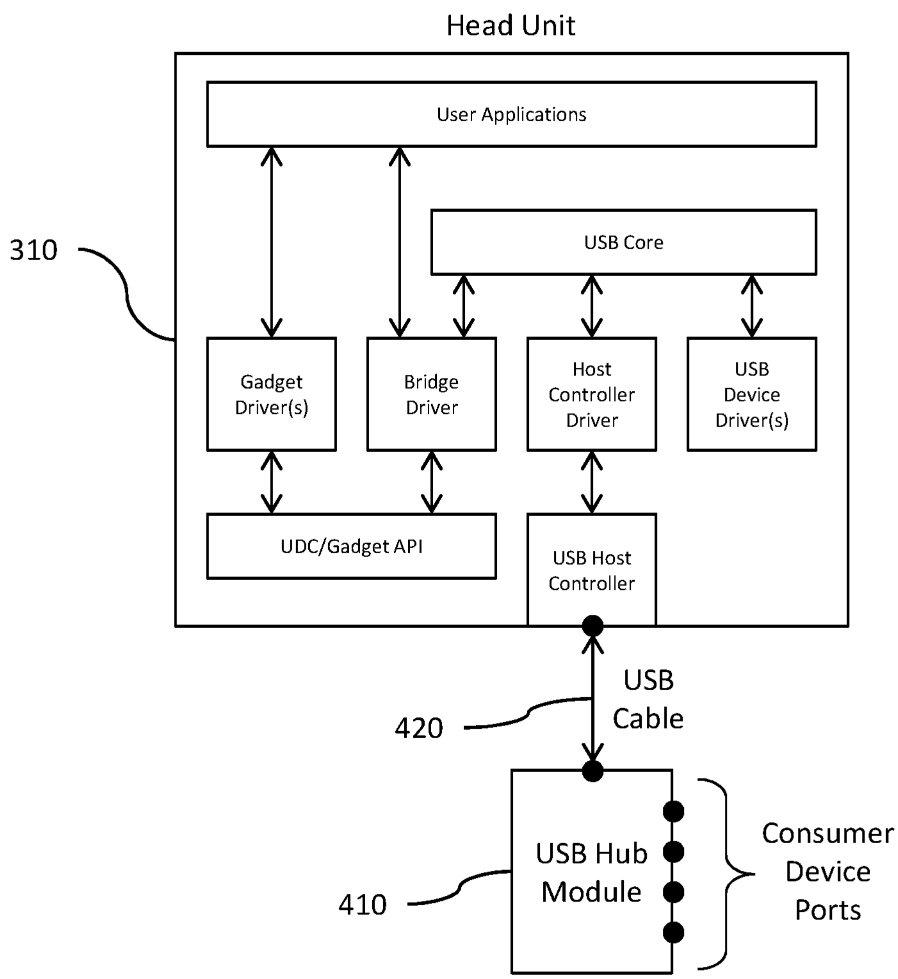
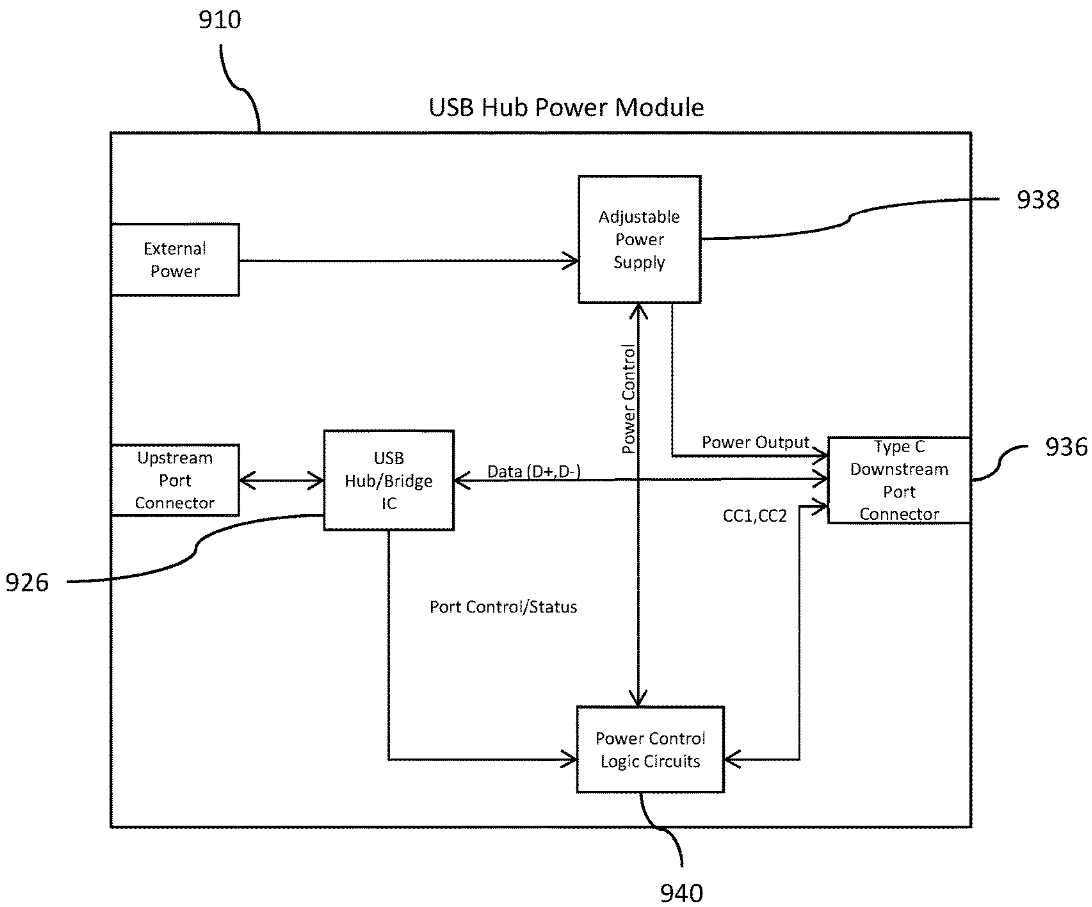

Head Unit
User Applications
USB Core
310
Gadget Driver(s)
Bridge Driver
Host Controller Driver
USB Device Driver(s)
UDC/Gadget API
USB Host Controller
USB Cable
420
USB Hub Module
410
Consumer Device Ports

Figure 8



910
USB Hub Power Module
External Power
Adjustable Power Supply
938
Power Control
Power Output
Upstream Port Connector
USB Hub/Bridge IC
Data (D+,D-)
Type C Downstream Port Connector
936
CC1,CC2
926
Port Control/Status
Power Control Logic Circuits
940

Figure 9

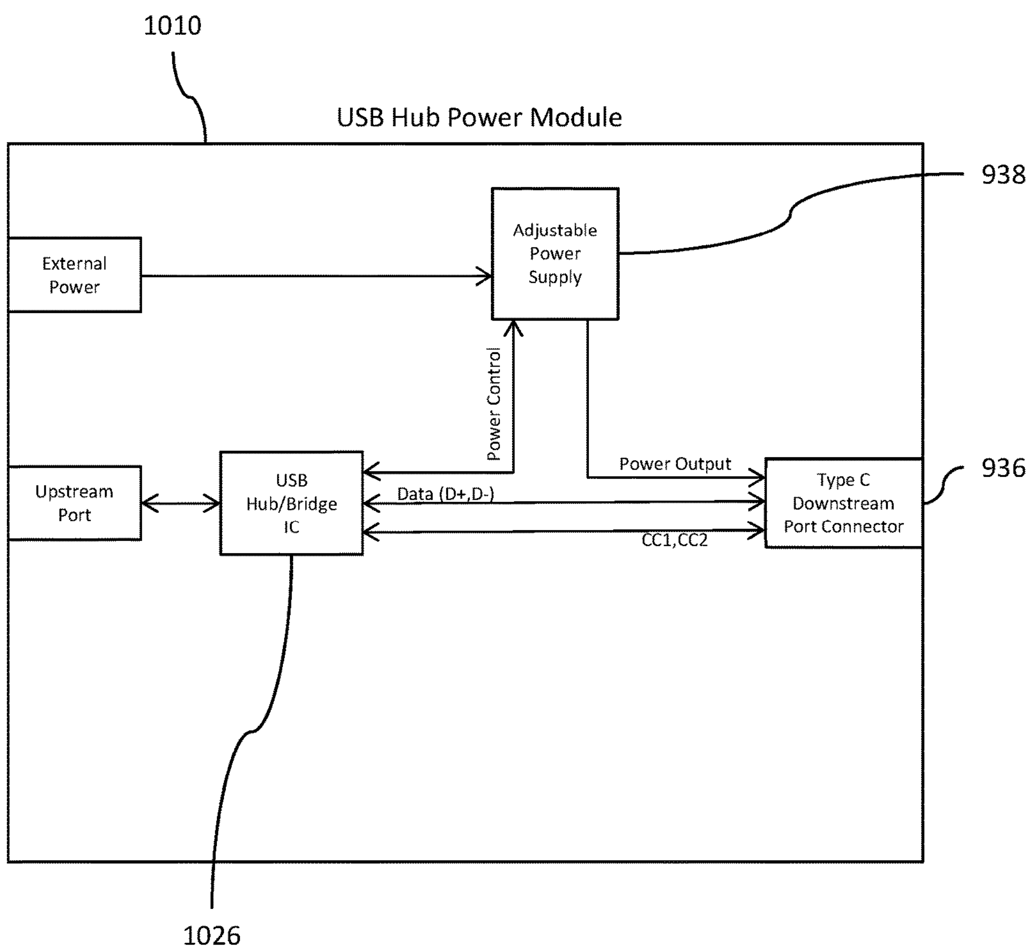

1010
USB Hub Power Module
938
Adjustable Power Supply
External Power
Power Control
Power Output
936
Upstream Port
USB Hub/Bridge IC
Data (D+,D-)
Type C Downstream Port Connector
CC1,CC2
1026

Figure 10

FLEXIBLE MOBILE DEVICE CONNECTIVITY TO AUTOMOTIVE SYSTEMS WITH USB HUBS

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part application and claims benefit under 35 U.S.C. §120 of U.S. patent application Ser. No. 14/487,947, filed Sep. 16, 2014, which claimed priority under 35 U.S.C. §119(e) of U.S. Provisional Patent Application No. 61/882,915, filed on Sep. 26, 2013, the entire disclosure of each of which are hereby incorporated herein by reference.

TECHNICAL FIELD OF THE INVENTION

The present invention generally relates to Universal Serial Bus (USB) connectivity between, for example, mobile consumer devices and vehicle electronic systems. More specifically, the present invention relates to a system which is configured to provide that consumer devices that act as either USB host or USB device can connect to a vehicle's embedded USB host that does not have USB On the Go (OTG) capability through an embedded USB hub in the vehicle.

BACKGROUND OF THE INVENTION

Historically, mobile consumer devices such as media players, smart phones, tablets and the like have relied on connections to other devices, such as laptop or desktop personal computers (PCs) to acquire content, exchange data, and charge the device's internal battery. For many years now, that has been accomplished through USB ports on each device. The use of USB technology is suitable for such needs since it is commonly available, familiar to the end user, cost effective and ubiquitous. USB protocols require a point-to-point connection in which one end is the USB host or master, and the other end is a USB device or slave. In this way, the flow of messages between the two devices is managed and controlled, whereby the USB device responds to messages initiated by the USB host. Historically, PCs have provided USB host ports for connection to simpler USB devices such as printers, memory sticks, mobile phones, etc. The USB host has a greater burden of software and hardware requirements than a USB device, so it has made sense to designate the PC as the USB host in such systems.

In vehicle systems that employ USB connections, the same concepts apply. In such systems, the vehicle is typically the USB host. The USB host function is often embedded into a component of the vehicle infotainment system, such as into the radio or other control module. Typically, multiple USB ports are strategically designed into the vehicle in locations convenient for the driver and passengers to connect their consumer devices. Once a consumer device is connected to one of the ports, the device begins charging and the vehicle infotainment system can access content on the consumer device. This is useful to enable features such as streaming music, video and other services the device may provide.

Such a system requires that each of the USB ports be physically connected to the vehicle's USB host in a manner suitable for USB data flow. This is accomplished through electrical cabling which is embedded in the vehicle, and which connects each of the ports to the USB host. Since there can be many USB ports in a vehicle, and each port

requires a cable to connect the port to the USB host, it is desirable to share cabling when possible to minimize cost and mass of the vehicle. This is accomplished through the use of USB hubs. USB hubs allow a single USB host to connect to multiple USB devices over a single cable between the USB host and the USB hub. As shown in FIGS. **1** and **2**, a single USB hub can connect one USB host to several USB devices. Specifically, FIG. **1** illustrates a system wherein a self-powered USB hub module **110** having a plurality of USB ports **112** connects to a plurality of USB devices via a plurality of consumer-facing USB ports **114**, while FIG. **2** illustrates a system wherein a self-powered USB hub module **210** provides not only a plurality of USB ports **212** which are in communication with a plurality of consumer-facing USB ports **214**, but also a Secure Digital (SD) card reader **216** which is connected to a consumer-facing SD card connector **218**. Other portions of FIGS. **1** and **2**, such as Power Management **116**, **220**, are standard in the industry and self-explanatory upon viewing FIGS. **1** and **2**.

Furthermore, as shown in FIG. **3**, multiple USB hubs can be tiered, such that USB hubs connect to other USB hubs. Specifically, FIG. **3** illustrates a vehicle system architecture that includes a central vehicle microcontroller **310** (also referred to as the head unit **310**). Connected to the head unit **310** are components or systems such as displays **312**, the audio or entertainment system **314**, and the driver controls **316**. The head unit **310** may be architected as a single module encompassing all functions or distributed such that various functions are managed by individual modules. The head unit **310** includes a Root USB hub **318** which is typically connected to one or more downstream USB hubs **320** A-D distributed throughout the vehicle. Each USB hub **320** has a plurality of downstream ports **322** (at least one of which may be an SD reader **324** or USB audio device—not shown), thereby effectively providing that each USB port **320** A-D in the vehicle has a connection to the USB host **318** or head unit **310**. In FIG. **3**, for example, the Root Hub is embedded in the radio, and is connected to four (4) self-powered USB hubs **320** A-D, wherein one is in the vehicle's center console **320**A, one is in the vehicle's center stack **320**B, and two are in the vehicle's rear seats **320**C, **320**D.

Recently, mobile devices such as smart phones have gained in popularity. This is, in part, due to their usefulness as standalone computing devices. With advances in consumer electronic technology and increases in the speed of mobile networks, these devices are no longer reliant on being connected to PCs to access content. These smart mobile devices now have many of the same hardware resources, connectivity and software operating systems that only PCs had in past years. As has been the case with desktop PCs, accessories for these mobile devices have become available to aid in their ease of use. These accessories have included devices such as keyboards, mice, displays, touchscreen, audio systems, and other interface devices. These accessories commonly connect via a USB connection. By way of established convention in the consumer electronics market, these accessories are typically low cost and limited in USB capability to act only as a USB device. To connect them to a smart phone, the smart phone must be the USB host. Therefore, leading mobile device manufacturers and system designers have begun designing their mobile device products (i.e. smart phones, tablets, etc.) to support both USB host and USB device roles. In other words, the phone may configure itself such that it can function as a USB device when it needs to be, or as a USB host when it needs to be. Recently, the system level design thinking has shifted towards viewing smart phones as the

USB host, and any device connecting thereto as the USB device. Again, this is not surprising since this is exactly how laptops and PCs work today. Extending this trend into the future, it can be predicted that the smart phone will act primarily as the USB host, and will rarely or never act as a USB device. This presents some problems for automotive systems.

As explained previously, automotive systems have a USB host and require USB devices to connect to it. If a phone acts as a USB host, then the system will not function since by USB convention, two USB hosts cannot directly connect with each other. Automotive manufacturers desire compatibility with smart phones and are therefore motivated to adapt to this changing technology. A redesign of the USB architecture in the vehicle is thus necessary such that the vehicle can act either as the USB host (when necessary to connect to USB devices such as memory sticks, thumb drives, etc.) or USB device (when necessary to connect to USB hosts, such as a smart phone which demands to be USB host rather than USB device.

The USB organization has added a standard that addresses the need for devices to act as either USB host or USB device and as such can be considered a "dual role" USB controller. It is referred to in USB nomenclature as "On The Go" or "OTG" for short. Any device that meets the OTG standard can act as either USB host or USB device and can change roles dynamically. Therefore, one possible approach to modifying the vehicle USB architecture to support all use cases is to upgrade the vehicle's USB host to USB OTG. This solution addresses the issue but has some disadvantages. First, USB hubs do not support OTG and can no longer be used in the system. Each consumer accessible USB port that supports OTG must have a dedicated wire link to a dedicated OTG controller in the head unit thus negating the wiring savings associated with use of USB hubs. As a result several costly cables may need to be added to the vehicle's electrical system. Second, there may not be enough OTG controllers available in the head unit to connect to each of the vehicle's user accessible USB ports. This then forces the vehicle designer to choose a limited number of the many USB ports in the vehicle to support the OTG function and run dedicated USB cables to them. This can lead to user confusion and dissatisfaction since only certain consumer ports support the required functionality. Also, ports that support OTG may be co-located with other physically identical ports that do not. If the user chooses the wrong one, the applications they desire to run from the consumer device that requires USB host mode won't work.

Another possible solution is to implement custom USB hubs wherein the USB hub is able to dynamically swap its upstream port with one it's downstream ports when commanded to do so. System solutions built with this concept still require OTG controllers in the head unit but benefit from the fact that no additional wires need to be installed in the car. The existing USB cable between the USB OTG host and the USB hub can facilitate the necessary USB communications between the USB OTG controller in the head unit and a consumer device in USB host (such as a smart phone). This solution also has some disadvantages however. For example, when the USB hub is commanded to swap it's upstream port with a downstream port, all other downstream ports of the USB hubs lose their data connection with the head unit. While in this mode the head unit access to the other downstream ports of the USB hub cease. This may prevent use of certain vehicle system functions such as navigation or audio playback that may need consistent access to the other downstream ports of the hub to function.

Furthermore, it requires the head unit to have an available USB OTG port and a signaling path to control the hub upstream/downstream port configuration.

The subject matter discussed in the background section should not be assumed to be prior art merely as a result of its mention in the background section. Similarly, a problem mentioned in the background section or associated with the subject matter of the background section should not be assumed to have been previously recognized in the prior art. The subject matter in the background section merely represents different approaches, which in and of themselves may also be inventions.

BRIEF SUMMARY OF THE INVENTION

According to an embodiment of this invention, a Universal Serial Bus (USB) hub module is provided. The USB hub module includes an upstream USB port configured to be interconnected to a USB host and a plurality of downstream USB ports configured to be interconnected to a plurality of USB enabled consumer devices. The USB hub module also includes a USB hub that is interconnected to the upstream USB port and the plurality of downstream USB ports. The USB hub is configured to broadcast data from the upstream USB port to each downstream USB port and to transmit data from each downstream USB port to the upstream USB port. The USB hub module further includes a USB bridge interconnected to the USB hub that is configured to connect the upstream USB port to a USB host and a USB routing switch interconnected to the USB bridge, the USB hub, and the plurality of downstream USB ports. The USB routing switch is configured to connect a first downstream USB port of the plurality of downstream USB ports to the upstream USB port through the USB bridge when a consumer device connected to the first downstream USB port is the USB host. The USB routing switch is further configured to initiate bidirectional communication with the upstream USB port. The USB routing switch is configured to connect the first downstream USB port directly to the USB hub when the consumer device connected to the first downstream USB port is configured to only respond to communication from the upstream USB port, thereby rendering the consumer device compatible with a device connected to the upstream USB port.

The USB routing switch may be configured to connect the first downstream USB port to the USB hub through the USB bridge when a first consumer device connected to the first downstream USB port is acting as the USB host. The USB routing switch is configured to simultaneously connect a second downstream USB port of the plurality of downstream USB ports directly to the USB hub when a second consumer device connected to the second downstream USB port is acting as a USB device, thereby rendering the first and second consumer devices compatible to communicate simultaneously with the upstream USB port.

The USB hub module may be configured to recognize whether the consumer device connected to the first downstream USB port is configured to act as the USB host or as a USB device and control the USB routing switch accordingly.

The USB hub module may be configured to dynamically switch operation of the plurality of downstream USB between a USB device mode and a USB host mode.

The USB routing switch may be configured to connect the consumer device to either the USB bridge or the USB hub based on whether the consumer device attached to each

downstream USB port in the plurality of downstream USB ports is configured to act as the USB host or a USB device.

The USB routing switch may include a plurality of USB analog multiplexing switches. The USB routing switch may include digital routing logic

The USB bridge may be configured to control the USB routing switch and may include a bridge controller as well as endpoint buffers. The endpoint buffers may be configured to support a USB data connection pipe between an infotainment system and the consumer device.

The USB hub module may further include a logic circuit configured to provide data handshaking to negotiate electrical power transfer from the USB hub module to a first consumer device that is connected to the first downstream USB port. The USB hub module may also include a power supply circuit configured to provide electrical power from the USB hub module to the first consumer device. The logic circuit may include a communication control stack. The power supply circuit may include adjustable voltage power supplies.

According to another embodiment of the invention, an integrated circuit (IC) is provided. The integrated circuit includes a USB hub that is configured to be interconnected to an upstream USB port and a plurality of downstream USB ports. The USB hub is configured to broadcast data from the upstream USB port to each downstream USB port and to transmit data from each downstream USB port to the upstream USB port. The IC also includes a USB bridge interconnected to the USB hub and configured to connect the upstream USB port to a USB host and a USB routing switch interconnected to the USB bridge, the USB hub, and the plurality of downstream USB ports. The USB routing switch is configured to connect a first downstream USB port of the plurality of downstream USB ports to the upstream USB port through the USB bridge when a consumer device connected to the first downstream USB port is the USB host. The USB routing switch is further configured to initiate bidirectional communication with the upstream USB port. The USB routing switch is configured to connect the first downstream USB port directly to the USB hub when the consumer device connected to the first downstream USB port is configured to only respond to communication from the upstream USB port, thereby rendering the consumer device compatible with a device connected to the upstream USB port.

The USB routing switch may be configured to connect the first downstream USB port to the USB hub through the USB bridge when a first consumer device connected to the first downstream USB port is acting as the USB host. In this instance, the USB routing switch is configured to simultaneously connect a second downstream USB port of the plurality of downstream USB ports directly to the USB hub when a second consumer device connected to the second downstream USB port is acting as a USB device, thereby rendering the first and second consumer devices compatible to communicate simultaneously with the upstream USB port.

The USB routing switch may be configured to connect the consumer device to either the USB bridge or the USB hub based on whether the consumer device attached to each downstream USB port in the plurality of downstream USB ports is configured to act as the USB host or a USB device. The USB bridge may be configured to control the USB routing switch.

The IC may further include a logic circuit that is configured to provide data handshaking to negotiate electrical power transfer from the USB hub module to a first consumer

device connected to the first downstream USB port. The logic circuit may include a communication control stack.

Still other embodiments are entirely possible, some of which are described and illustrated herein. For example, the concept can be extended to include additional embedded USB device functions such as USB HID and USB Audio. Further it is also envisioned that all consumer facing USB ports of the USB hub module can emulate or otherwise support dual role USB capability provided that each downstream port has a Bridge to support USB host mode for the connected device and a direct connection to the USB hub to support USB device mode. In all cases, compliance to USB protocols and architectures is preferably maintained.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

The organization and manner of the structure and operation of the invention, together with further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawings wherein like reference numerals identify like elements in which:

FIG. **1** illustrates a system wherein a multiple port self-powered USB hub functions to connect a single USB host to a plurality of USB ports;

FIG. **2** illustrates a system wherein a self-powered USB hub provides not only a plurality of USB ports, but also a Secure Digital (SD) card reader;

FIG. **3** illustrates a vehicle infotainment system structure wherein multiple USB hubs are connected together or tiered, such that USB hubs feed other USB hubs;

FIG. **4** illustrates a system which is in accordance with an embodiment of the present invention, wherein a USB hub, USB bridge and a switching device are provided as discrete components;

FIG. **5** illustrates a system which is in accordance with an alternative embodiment of the present invention, wherein USB routing/switching logic and a USB bridge are integrated with a USB hub in a combination USB hub/bridge integrated circuit (IC);

FIG. **6** illustrates the different components of the combination USB hub/bridge IC shown in FIG. **5**;

FIG. **7** illustrates one possible endpoint configuration of the USB bridge shown in FIGS. **5** and **6**;

FIG. **8** illustrates an example implementation of a head unit software architecture;

FIG. **9** illustrates an example of a USB hub power module; and

FIG. **10** illustrates another example of a USB hub power module.

DETAILED DESCRIPTION OF THE INVENTION

While this invention may be susceptible to embodiment in different forms, there are specific embodiments shown in the drawings and will be described herein in detail, with the understanding that the present disclosure is to be considered an exemplification of the principles of the invention, and is not intended to limit the invention to that as illustrated.

FIG. **4** illustrates a system which is in accordance with an embodiment of the present invention. The system is configured to effectively render a vehicle's embedded USB host compatible with consumer devices which are configured to also act as USB host or USB device. The system is in the form of a self-powered USB hub module **410** having a USB

hub **412**, a USB bridge **414**, and a switching device **416** implemented as discrete devices. The USB hub **412** is preferably provided in the form of an integrated circuit (IC), and is configured (via an upstream USB port **418**) connected to a vehicle's embedded USB host (such as a USB host in a head unit—not shown) via vehicle internal wiring, such as, in one embodiment, via a single USB data cable **420** between the head unit and USB hub **412**. The USB hub **412** also includes a plurality of downstream USB ports **422**, at least one of which is connected to the USB bridge **414** (which also is preferably provided in the form of an integrated circuit (IC)). At least one downstream USB port **422** of the USB hub **412** is connected to the switching device **416** (such as USB analog multiplexing switches, for example). The switching device **416** is configured to be connected to at least one USB port **422** in the vehicle for connection to a consumer device. The USB bridge **414** is configured to effectively control the switching device **416** although other control mechanisms are envisioned. The USB hub module **410** is configured such that signals received from at least one USB port **422** are received by the switching device **416**, and the switching device **416** routes the signals to the USB bridge **414** or the USB hub **412**. In the case where the consumer device is acting as USB host, the USB bridge **414** processes the USB packets from the downstream USB port **422** and provides them to the USB hub **412**, thereby rendering the consumer device compatible with the vehicle's embedded USB host. In the case where the consumer device is acting as USB device, the USB bridge **414** controls the switching device **416** such that the switching device **416** provides the USB signaling directly to the USB hub **412**, bypassing the USB bridge **414**.

As shown in FIG. **4**, the system also includes Power Management structure **424**, as well as some other conventional structure not specifically shown in FIG. **4**, but which would be readily assumed to be present by one having ordinary skill in the art.

In use, the head unit controls the switching device **416** via the USB bridge hardware or any other convenient means of control. The head unit software application may choose to enable, for example, a phone on any one of the consumer USB ports, by requesting, commanding or otherwise knowing the phone is required to be in USB host mode and commanding the routing of the specific USB port the phone is attached to the USB bridge **414**. Once routed to the USB bridge **414**, the phone will detect a USB device is connected and the phone will begin the standard USB enumeration sequence. The detection and enumeration processes are defined by USB standards and not explained here in detail. However, for purposes of describing the operation of the invention, a general understanding is provided herein. The enumeration process follows a strict sequence of USB descriptor requests from the USB host and USB descriptor responses from the USB device that allow the Host to determine the capabilities and functions of the USB device and configure the USB device for operation. Once the complete set of device descriptors are known the USB host will then load the appropriate USB driver(s) and applications to support in the functionality that the USB device provides. In the scope of this invention it is envisioned that the responses to the descriptor requests made by the phone (USB host) are either answered locally by the Bridge or preferably, the requests are forwarded through the USB bridge **414** to the head unit where its device drivers process the request and return the response. The descriptor responses from the device driver are conveyed to the USB bridge **414**, which then, in turn, passes them to the phone. By passing descriptor request to the head unit drivers and returning the responses from the head unit drivers back to the consumer device, the USB bridge **414** appears as a transparent component in the USB system architecture. The system capabilities are controlled by the head unit and the system remains flexible without need for changes to the USB bridge firmware or hardware when the system designer requires changes to the descriptor responses. Once the consumer device completes the enumeration process, the head unit's USB functional capabilities are known to the consumer device and the consumer device may enable use of those functions over USB communication. At this point, the consumer device or the head unit may begin activating any number of supported services such as data connections, streaming audio and streaming video to and from the vehicle via the USB bridge **414**.

Another embodiment of the present invention can be provided, wherein the bridge is configured to act as an OTG port thus negating the need for switches and/or routing logic. In this case there would exist one Bridge functional block for each downstream port. This embodiment would effectively be a more generalized case of the example illustrated in FIG. **4**. FIG. **4** shows just one USB bridge **414** that any one of the downstream USB ports **422** can be routed to. With just one USB bridge **414**, only one downstream USB port **422** can be connected to a USB host at a time. However, if each downstream port of the USB hub has a dedicated USB bridge, then multiple downstream ports can support connection to USB host devices at the same time. Thus, any consumer port can be in either USB host or USB device mode at any time independently of the others.

FIG. **5** illustrates an alternative embodiment of a USB hub module **510** wherein the switching device **516** comprises USB routing logic, and both the switching device **516** and the USB bridge **514** are integrated with the USB hub **512** in a combination USB hub/bridge integrated circuit (IC) **526**. This configuration has cost and size advantages over building it with discrete components connected together on a printed circuit board.

FIG. **6** illustrates the internal components of the USB hub/bridge IC **526** shown in FIG. **5**. As shown, preferably the components of the USB bridge **614** include a bridge controller **628** as well as endpoint buffers **630**. While the exact configuration of endpoints is effectively up to the system designer to choose for a particular need, a specific example of one possible endpoint configuration is shown in FIG. **7**; however, many others are possible.

As shown in FIG. **7**, the endpoints of the USB bridge **614** may be designed to support multiple pipes of Bulk USB data connections between the host A (head unit) and host B (consumer device). In the USB bridge **614**, the IN endpoints of device A are connected to the OUT endpoints of device B and the OUT endpoints of device A **732** are connected to the IN endpoints of device B **734**. The design of the USB bridge **614** may be such that the data flow between the endpoints may be direct or buffered. For example, in the case of direct connection, once a USB packet is received from host A on a device A OUT endpoint, the internal logic of the USB bridge **614** moves to packet to the device B IN endpoint if it is available. If device B IN endpoint is full or otherwise not available then subsequent attempts of Host A to send more packets to device A in the USB bridge **614** will be rejected until such time that the device B IN endpoint is clear and the contents of the device A OUT buffer is moved to it. Alternatively, there may exist a local buffer in the USB bridge **614** between the endpoints of device A and B. For example, packets received on an OUT endpoint of device A

are placed in a local memory device for temporary storage until device B IN endpoint is ready for them. The OUT endpoints are thus capable of receiving multiple packets from the Host until the buffer is full. Likewise the IN endpoints may, at times, transmit multiple packets until the buffer is empty. Such buffers are not required, but are envisioned, to improve system throughput performance in certain circumstances where one of the USB hosts is occasionally busy and not keeping up with USB transactions at the same rate as the other USB host. Regardless of the buffer configuration, the USB bridge hardware has IN and OUT endpoints on device A mapped to OUT and IN endpoints respectively on device B, thus forming a bidirectional bridge that passes USB traffic between two USB hosts with bandwidth sufficient to support the application requirements of the system.

Also shown in FIG. **7**, device A **732** and device B **734** provide a bidirectional control endpoint connected to their respective USB hosts. Control endpoints are required per the USB standard to support USB defined control messages between the host and device both during and after the enumeration sequence. Optionally, USB endpoints may also be utilized per USB standard to employ messages intended to control user defined custom device specific behavior, referred to as vendor specific messages. As can be seen in FIG. **7**, the control endpoints are mapped to the bridge controller **628**. The BC logic may be implemented in hardware or preferably software. The bridge controller **628** provides the capability to send, receive and process USB standard control endpoint messages as well as vendor specific messages essential to the control and operation of the USB bridge **614**. At system startup, host A requests and receives descriptors from the bridge controller **628** via the control endpoint. Once complete, host A then loads the bridge driver in its software stack and configures the custom Bridge hardware for operation. Host A can then control the functions of the USB bridge **614**, such as USB switch routing control. The system is now ready to accept connection with USB host mode consumer devices on device B **734** of the USB bridge **614**. When such a connection is made, the bridge controller **628** will notify the bridge driver in host A by sending a message on the control endpoint to host A. Further, host B will begin sending descriptor requests on the control endpoint to device B **734** in the USB bridge **614**. The bridge controller **628** receives theses requests, encapsulates them with information that identifies them as descriptor requests from host B and passes them to the bridge driver on host A using the control endpoint. The host A bridge driver receives these requests, identifies them as descriptor requests and passes the requests on to other software components in host A system and waits for the descriptor responses. The descriptor responses are encapsulated by the bridge driver to indicate they are descriptor responses that are to be forwarded to host B. The response is then sent to the bridge controller **628** via the control endpoint. The bridge controller **628** receives them, identifies them as descriptor responses that should be forwarded to device B and places them on the control endpoint for device B **734**. This process of receiving and forwarding messages back and forth between the two hosts continues until the enumeration process is complete with host B. From that point on the two hosts may begin to use the IN and OUT endpoints to transfer application data and services over the bulk endpoints.

FIG. **8** illustrates one possible configuration of the system architecture including software components in the head unit **310** interfacing with the USB hub module **410**. There are multiple ways that the operating system and software architecture can be constructed to support the functions of the USB hub module **410**. In FIG. **8**, a typical Linux implementation is shown including the USB hub module **410** and the head unit **310**. The system design utilizes standard Linux kernel components and configurations and should be familiar to those skilled in the art. The head unit's USB host controller hardware is driven by the host controller driver. the host controller driver is connected to the USB core. The USB core connects the host controller driver with the standard USB Linux device drivers and the custom bridge driver. The bridge driver is configured to optionally connect directly to the user space application software or to the USB gadget driver depending on system architecture. The custom bridge driver plays a dual role of both controlling the functions of the bridge hardware as well as providing a data path between the gadget device drivers and applications running on the head unit **310**. The architecture illustrated is capable of handling both the operation and data paths associated with the USB bridge **414** and the USB hub **412** at the same time, thus allowing concurrent operation of consumer devices operating in USB device mode with consumer devices operating in USB host mode. In one embodiment, the USB hub module **410** supports simultaneous active USB data connections between the head unit **310** and multiple consumer devices, at least one of which being in host mode while the others are in device mode. In another embodiment, the USB hub module **410** supports simultaneous active USB data connections between the head unit **310** and some combination of embedded and consumer USB devices along with at least one device being in host mode. While it is understood that the software functions of the head unit **310** are essential to building a complete system, the designs of which can vary significantly and this example is provided only as a means of demonstrating one way to utilize the functionality of the present invention.

FIG. **9** illustrates a USB hub power module **910** that includes USB power delivery capability as described USB Power Delivery Specification Rev. 3.0 v1.0 published Mar. 25, 2106 by the USB Implementer's Forum, Inc. This technology provides the means for the USB hub power module **910** to provide greater charging capabilities to the consumer devices connected to the downstream ports. The USB hub power module **910** has at least one downstream port connector **936** that conforms to the USB Type C standard as described in the USB Type-C Cable and Connector Specification, Revision 1.2 published Mar. 25, 2106 by the USB Implementer's Forum, Inc. In addition to the functions of the USB hub module **410**, **510**, or **610** discussed above, this USB hub power module **910** further includes adjustable voltage power supplies **938**, power control logic circuits **940** to facilitate handshaking over the CC**1** and CC**2** pins, and a communication control stack that is integral to the logic circuits. The USB Type-C connector requirements include data transmissions between the electrical power provider (source) and the electrical power consumer (sink) on CC**1** and CC**2** pins defined in the USB Type C standard as a handshaking function. The source in this case is the USB hub power module **910** and the sink is the consumer device (not shown) connected to the downstream port connector **936**. To facilitate the handshake function on the CC1 and CC**2** pins, additional logic circuits in the form of separate discrete IC's and passive components may be added to the USB hub power module **910** as shown in FIG. **9**. To facilitate the handshake function on the CC**1** and CC**2** pins and control the adjustable power supplies **938**, additional logic circuits may be added to the USB hub power module **910** in the form of separate discrete IC's and passive

components. Preferably, the logic circuits, communication stack, and physical layer interface functions would be integrated in the USB hub/bridge IC **926**, thereby reducing bill of material costs and manufacturing costs.

As alternate embodiment of the USB hub power module **1010** is shown in FIG. **10**. The power control logic circuits are further integrated in a USB hub/bridge IC **1026**, thereby further reducing bill of material costs and manufacturing costs.

While this invention has been described in terms of the preferred embodiments thereof, it is not intended to be so limited, but rather only to the extent set forth in the claims that follow. Moreover, the use of the terms first, second, etc. does not denote any order of importance, but rather the terms first, second, etc. are used to distinguish one element from another. Furthermore, the use of the terms a, an, etc. do not denote a limitation of quantity, but rather denote the presence of at least one of the referenced items.

We claim:

1. A Universal Serial Bus (USB) hub module, comprising:

an upstream USB port;

a plurality of downstream USB ports;

a USB hub interconnected to the upstream USB port and the plurality of downstream USB ports, said USB hub configured to broadcast data from the upstream USB port to each downstream USB port and to transmit data from each downstream USB port to the upstream USB port;

a USB bridge interconnected to the USB hub and configured to connect the upstream USB port to a USB host; and

a USB routing switch interconnected to the USB bridge, the USB hub, and the plurality of downstream USB ports, wherein the USB routing switch is configured to connect a first downstream USB port of the plurality of downstream USB ports to the upstream USB port through the USB bridge when a consumer device connected to the first downstream USB port is the USB host and is configured to initiate bidirectional communication with the upstream USB port, and wherein the USB routing switch is configured to connect the first downstream USB port directly to the USB hub when the consumer device connected to the first downstream USB port is configured to only respond to communication from the upstream USB port, thereby rendering the consumer device compatible with a device connected to the upstream USB port.

2. The USB hub module according to claim **1**, wherein the USB routing switch is configured to connect the first downstream USB port to the USB hub through the USB bridge when a first consumer device connected to the first downstream USB port is acting as the USB host, and wherein the USB routing switch is configured to simultaneously connect a second downstream USB port of the plurality of downstream USB ports directly to the USB hub when a second consumer device connected to the second downstream USB port is acting as a USB device, thereby rendering the first and second consumer devices compatible to communicate simultaneously with the upstream USB port.

3. The USB hub module according to claim **1**, wherein the USB hub module is configured to recognize whether the consumer device connected to the first downstream USB port is configured to act as the USB host or as a USB device and control the USB routing switch accordingly.

4. The USB hub module according to claim **1**, wherein the USB hub module is configured to dynamically switch operation of the plurality of downstream USB between a USB device mode and a USB host mode.

5. The USB hub module according to claim **1**, wherein the USB routing switch is configured to connect the consumer device to either the USB bridge or the USB hub based on whether the consumer device attached to each downstream USB port in the plurality of downstream USB ports is configured to act as the USB host or a USB device.

6. The USB hub module according to claim **1**, wherein the USB routing switch comprises a plurality of USB analog multiplexing switches.

7. The USB hub module according to claim **1**, wherein the USB bridge is configured to control the USB routing switch.

8. The USB hub module according to claim **1**, wherein the USB bridge comprises a bridge controller as well as endpoint buffers.

9. The USB hub module according to claim **8**, wherein the endpoint buffers are configured to support a USB data connection pipe between an infotainment system and the consumer device.

10. The USB hub module according to claim **1**, wherein the USB routing switch comprises digital routing logic.

11. The USB hub module according to claim **1**, wherein the USB hub module further comprises a logic circuit configured to provide data handshaking to negotiate electrical power transfer from the USB hub module to a first consumer device connected to the first downstream USB port, and wherein the USB hub module further comprises a power supply circuit configured to provide electrical power from the USB hub module to the first consumer device.

12. The USB hub module according to claim **11**, wherein the logic circuit includes a communication control stack.

13. The USB hub module according to claim **11**, wherein the power supply circuit includes adjustable voltage power supplies.

14. An integrated circuit, comprising:

a USB hub configured to be interconnected to an upstream USB port and a plurality of downstream USB ports, said USB hub configured to broadcast data from the upstream USB port to each downstream USB port and to transmit data from each downstream USB port to the upstream USB port;

a USB bridge interconnected to the USB hub and configured to connect the upstream USB port to a USB host; and

a USB routing switch interconnected to the USB bridge, the USB hub, and the plurality of downstream USB ports, wherein the USB routing switch is configured to connect a first downstream USB port of the plurality of downstream USB ports to the upstream USB port through the USB bridge when a consumer device connected to the first downstream USB port is the USB host and is configured to initiate bidirectional communication with the upstream USB port, and wherein the USB routing switch is configured to connect the first downstream USB port directly to the USB hub when the consumer device connected to the first downstream USB port is configured to only respond to communication from the upstream USB port, thereby rendering the consumer device compatible with a device connected to the upstream USB port.

15. The integrated circuit according to claim **14**, wherein the USB routing switch is configured to connect the first downstream USB port to the USB hub through the USB bridge when a first consumer device connected to the first downstream USB port is acting as the USB host, and wherein the USB routing switch is configured to simulta-

neously connect a second downstream USB port of the plurality of downstream USB ports directly to the USB hub when a second consumer device connected to the second downstream USB port is acting as a USB device, thereby rendering the first and second consumer devices compatible to communicate simultaneously with the upstream USB port.

16. The integrated circuit according to claim **14**, wherein the USB routing switch is configured to connect the consumer device to either the USB bridge or the USB hub based on whether the consumer device attached to each downstream USB port in the plurality of downstream USB ports is configured to act as the USB host or a USB device.

17. The integrated circuit according to claim **14**, wherein the USB bridge is configured to control the USB routing switch.

18. The integrated circuit according to claim **14**, wherein the integrated circuit further comprises a logic circuit configured to provide data handshaking to negotiate electrical power transfer from the USB hub module to a first consumer device connected to the first downstream USB port.

19. The integrated circuit according to claim **18**, wherein the logic circuit includes a communication control stack.

* * * * *

EXHIBIT C

US009460037B2

(12) **United States Patent**
Voto et al.

(10) **Patent No.: US 9,460,037 B2**
(45) **Date of Patent: Oct. 4, 2016**

(54) **FLEXIBLE MOBILE DEVICE CONNECTIVITY TO AUTOMOTIVE SYSTEMS WITH USB HUBS**

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(73) Assignee: **Delphi Technologies, Inc.**, Troy, MI (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/487,947**

(22) Filed: **Sep. 16, 2014**

(65) **Prior Publication Data**

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Related U.S. Application Data

(60) Provisional application No. 61/882,915, filed on Sep. 26, 2013.

(51) **Int. Cl.**
G06F 13/38 (2006.01)
G06F 13/40 (2006.01)

(52) **U.S. Cl.**
CPC ***G06F 13/385*** (2013.01); ***G06F 13/4022*** (2013.01); ***G06F 13/4045*** (2013.01); *G06F 2213/0042* (2013.01); *G06F 2213/4004* (2013.01)

(58) **Field of Classification Search**
CPC G06F 13/385; G06F 2213/3812; G06F 13/4022; G06F 13/4045; G06F 2213/4004; G06F 2213/0042
USPC 710/15
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,130,656	B2	10/2006	Okagaki et al.	
7,280,802	B2	10/2007	Grady	
7,478,191	B2	1/2009	Wurzburg et al.	
7,502,878	B1 *	3/2009	Wright	G06F 13/4022 710/37

(Continued)

OTHER PUBLICATIONS

Al-Ani, Tarik et al.; Android-based In-Vehicle Infotainment System (AIVI); IS PGD 2010, Oct. 26, 2010, Dunedin, New Zealand.

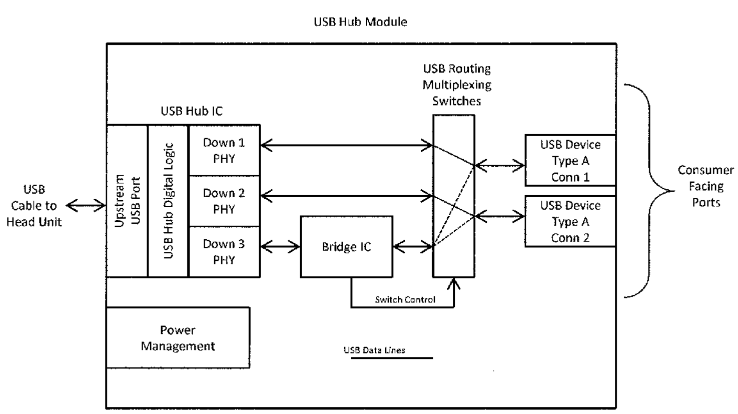
(Continued)

Primary Examiner — Ernest Unelus
(74) *Attorney, Agent, or Firm* — Robert J Myers

(57) **ABSTRACT**

A system which is configured to enable a vehicle's embedded USB Host system to connect to multiple mobile devices through a USB Hub, regardless of whether the mobile devices are configured to act as USB Hosts or USB Devices, without the need to add or provide OTG controllers in the system or additional vehicle wiring, or inhibiting the functionality of any consumer devices operating in USB Device mode connected to a vehicle system Hub while another consumer device connected to the same Hub operates in USB Host mode. Preferably, the system is configured to provide that no additional cabling is required, and no hardware changes are required to be made to the HU. The system can be employed between a vehicle's embedded USB Host, USB Hub and at least one consumer accessible USB port. In the case where the consumer device is acting as a USB Host, signals between the consumer device and the vehicle's embedded USB Host are processed through a bridge, thereby rendering the consumer device compatible with the vehicle's embedded USB Host.

17 Claims, 8 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

8,447,598	B2	5/2013	Chutorash et al.	
8,447,890	B1	5/2013	LeTourneur et al.	
2003/0167345	A1*	9/2003	Knight et al.	709/249
2006/0056401	A1	3/2006	Bohm et al.	
2006/0227759	A1*	10/2006	Bohm	G06F 13/4022 370/351
2007/0086724	A1	4/2007	Grady et al.	
2007/0156293	A1*	7/2007	Kellzi et al.	701/1
2008/0005262	A1	1/2008	Wurzburg et al.	
2009/0117890	A1	5/2009	Jacobsen et al.	
2010/0260350	A1	10/2010	Chutorash et al.	
2011/0054721	A1	3/2011	Goodrich et al.	
2011/0124300	A1	5/2011	Sinai	
2012/0134506	A1	5/2012	DeBiasio et al.	
2012/0191811	A1	7/2012	Ng et al.	
2012/0290859	A1	11/2012	Saladin et al.	
2013/0053003	A1	2/2013	King, II	
2013/0106750	A1	5/2013	Kurosawa	

OTHER PUBLICATIONS

Al-Ani, Tarik; Android In-Vehicle Infotainment System (AIVI); Jun. 2011, Dunedin, New Zealand.

Ellis, Brian; USB in Automotive: Not Just for PCs Anymore; Cypress Semiconductor Corp.; Sep. 7, 2006.

Koch, Niels; The Car Entertainment System; InTech; 2011.

* cited by examiner

Figure 1

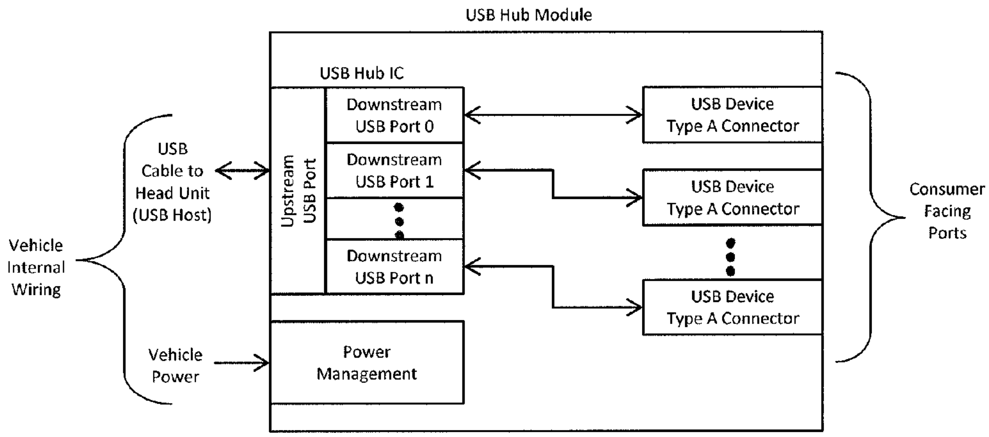

USB Hub Module
USB Hub IC
Upstream USB Port
Downstream USB Port 0
Downstream USB Port 1
Downstream USB Port n
USB Device Type A Connector
USB Device Type A Connector
USB Device Type A Connector
Power Management
USB Cable to Head Unit (USB Host)
Vehicle Power
Vehicle Internal Wiring
Consumer Facing Ports

Figure 2

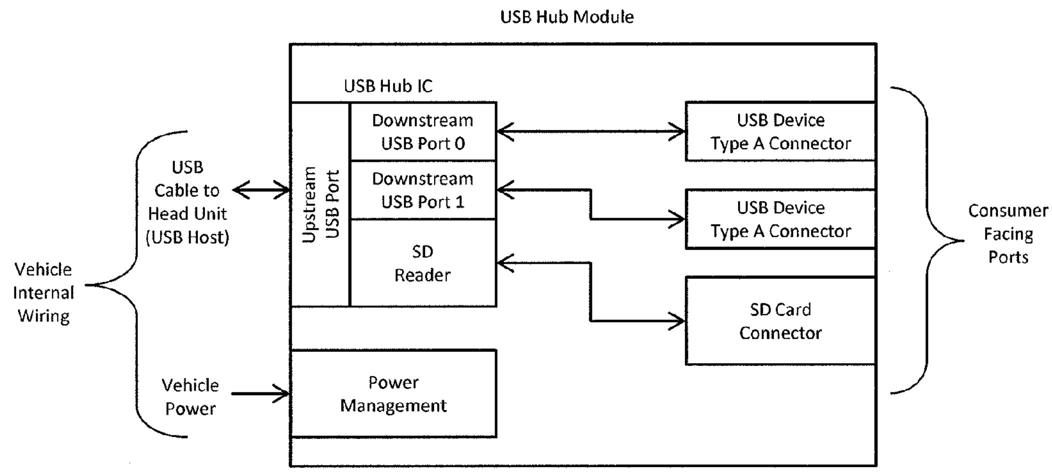
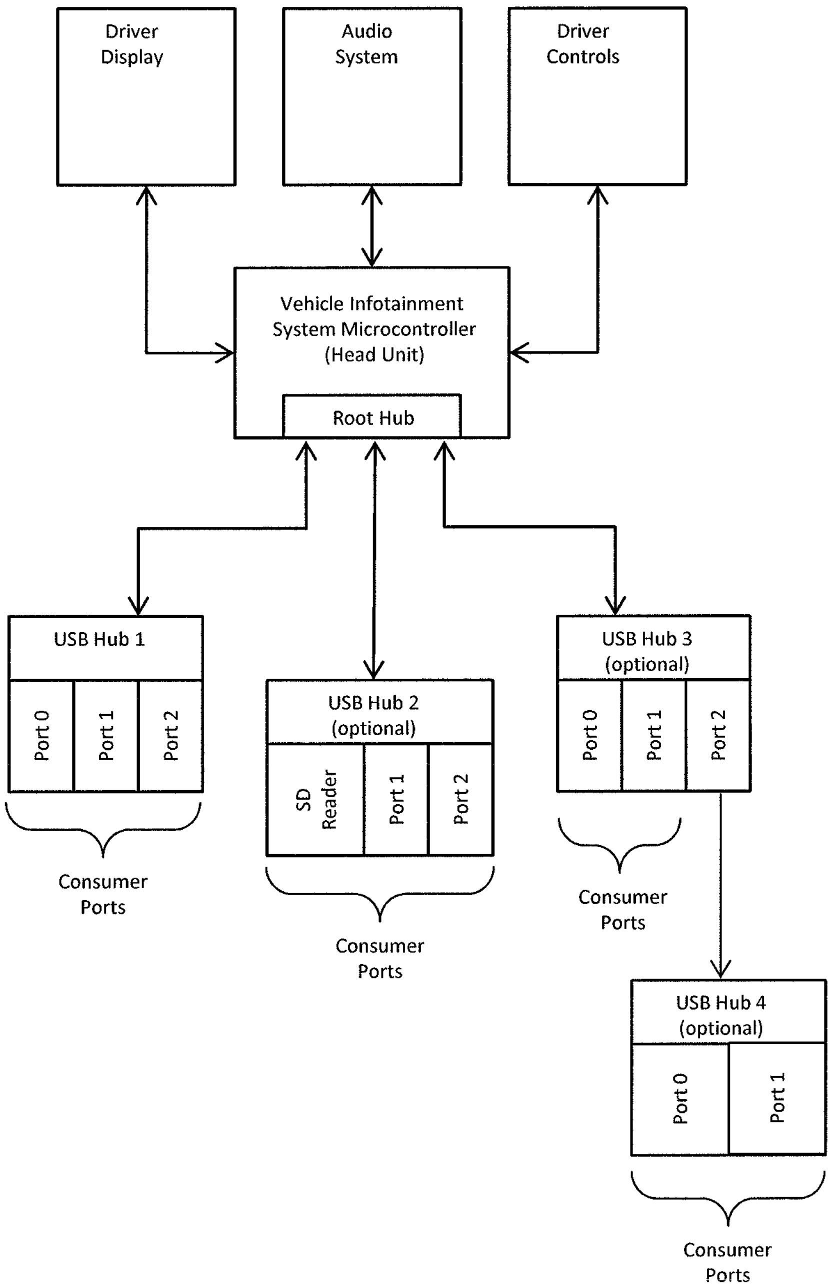

USB Hub Module
USB Hub IC
Upstream USB Port
Downstream USB Port 0
Downstream USB Port 1
SD Reader
USB Device Type A Connector
USB Device Type A Connector
SD Card Connector
Power Management
USB Cable to Head Unit (USB Host)
Vehicle Power
Vehicle Internal Wiring
Consumer Facing Ports

Figure 3



Driver Display
Audio System
Driver Controls
Vehicle Infotainment System Microcontroller (Head Unit)
Root Hub
USB Hub 1
Port 0
Port 1
Port 2
Consumer Ports
USB Hub 2 (optional)
SD Reader
Port 1
Port 2
Consumer Ports
USB Hub 3 (optional)
Port 0
Port 1
Port 2
Consumer Ports
USB Hub 4 (optional)
Port 0
Port 1
Consumer Ports

Figure 4

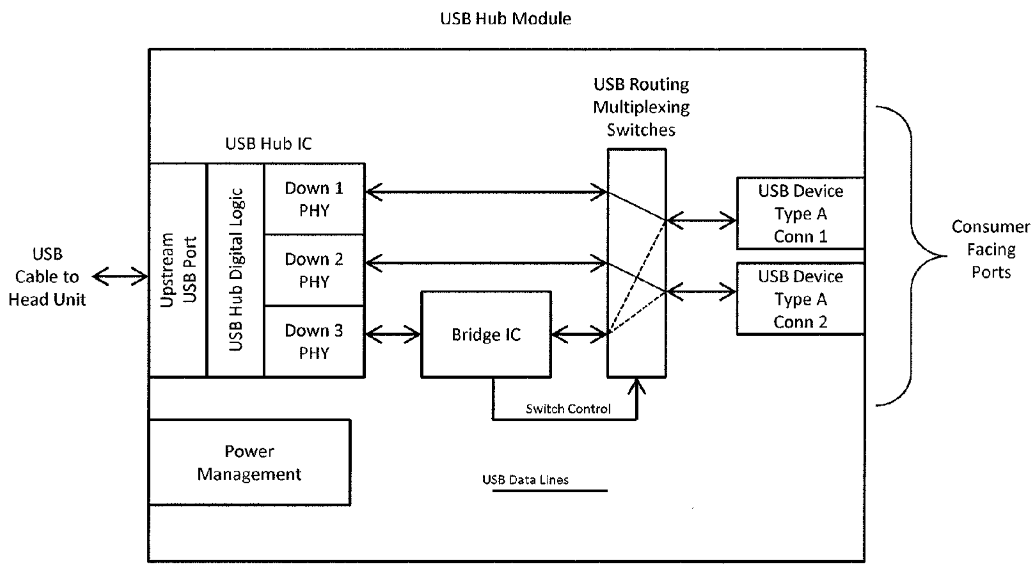

USB Hub Module
USB Routing Multiplexing Switches
USB Hub IC
Down 1 PHY
Down 2 PHY
Down 3 PHY
Upstream USB Port
USB Hub Digital Logic
USB Cable to Head Unit
Bridge IC
USB Device Type A Conn 1
USB Device Type A Conn 2
Consumer Facing Ports
Switch Control
Power Management
USB Data Lines

Figure 5

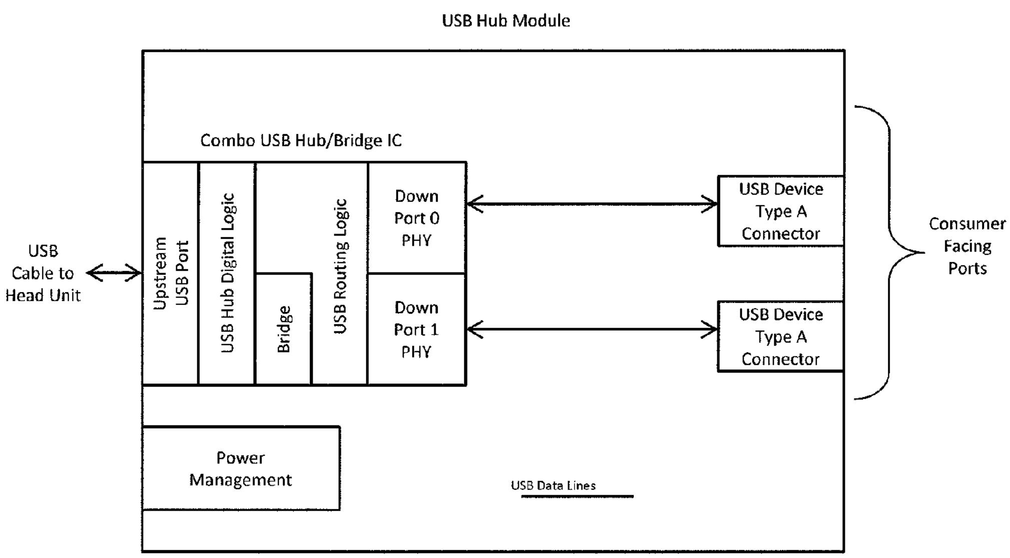

USB Hub Module
Combo USB Hub/Bridge IC
USB
Cable to
Head Unit
Upstream
USB Port
USB Hub Digital Logic
Bridge
USB Routing Logic
Down
Port 0
PHY
Down
Port 1
PHY
USB Device
Type A
Connector
USB Device
Type A
Connector
Consumer
Facing
Ports
Power
Management
USB Data Lines

Figure 6

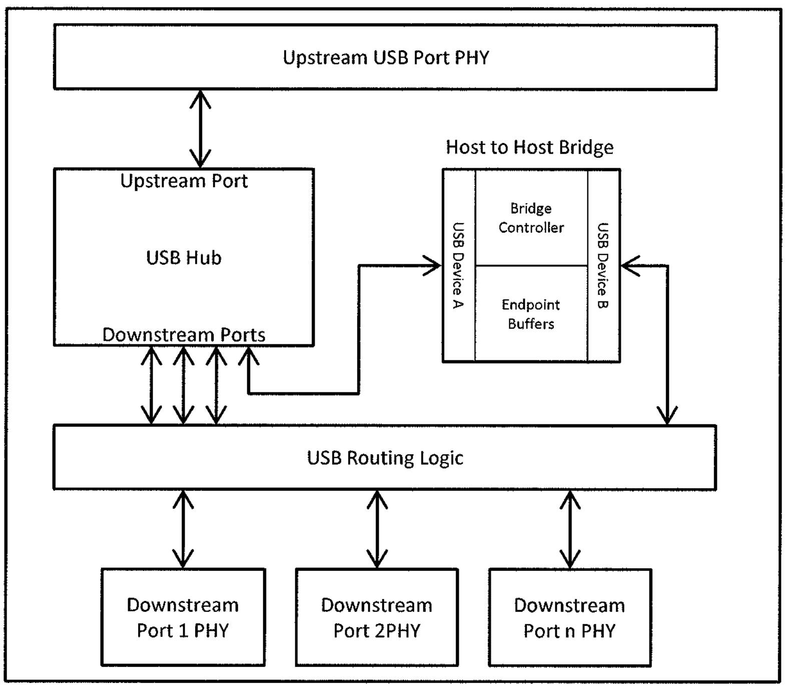

Upstream USB Port PHY
Host to Host Bridge
Upstream Port
USB Hub
Downstream Ports
USB Device A
Bridge Controller
Endpoint Buffers
USB Device B
USB Routing Logic
Downstream Port 1 PHY
Downstream Port 2PHY
Downstream Port n PHY

Figure 7

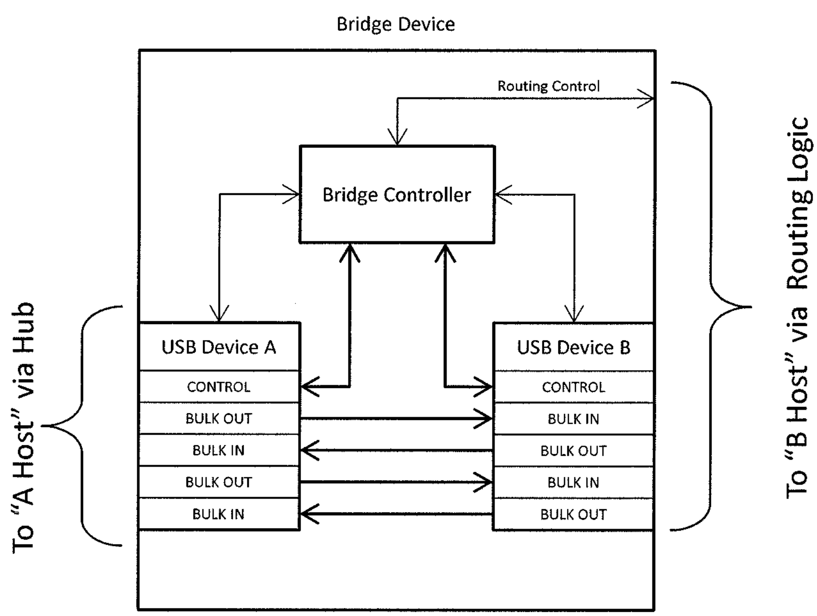
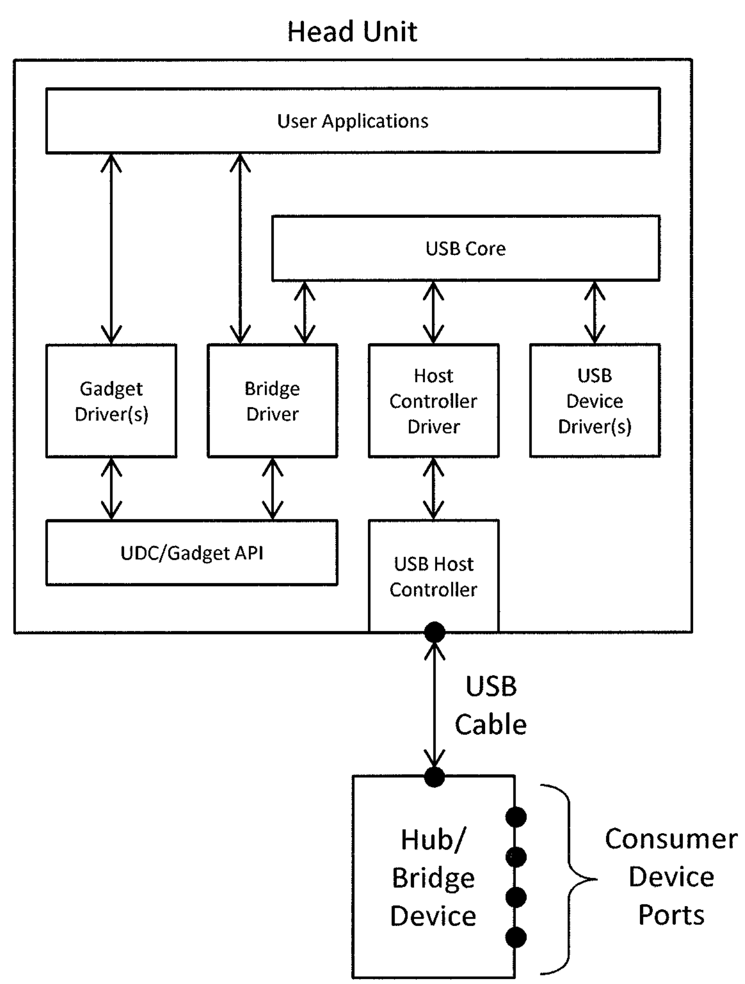

Bridge Device
Routing Control
Bridge Controller
USB Device A
CONTROL
BULK OUT
BULK IN
BULK OUT
BULK IN
USB Device B
CONTROL
BULK IN
BULK OUT
BULK IN
BULK OUT
To "A Host" via Hub
To "B Host" via Routing Logic

Figure 8


Head Unit
User Applications
USB Core
Gadget Driver(s)
Bridge Driver
Host Controller Driver
USB Device Driver(s)
UDC/Gadget API
USB Host Controller
USB Cable
Hub/ Bridge Device
Consumer Device Ports

FLEXIBLE MOBILE DEVICE CONNECTIVITY TO AUTOMOTIVE SYSTEMS WITH USB HUBS

RELATED APPLICATION

Priority Claim

This application claims the benefit of U.S. Provisional Application Ser. No. 61/882,915, filed on Sep. 26, 2013, which is hereby incorporated herein by reference in its entirety.

BACKGROUND

The present invention generally relates to Universal Serial Bus ("USB") connectivity between, for example, mobile consumer devices and vehicle electronic systems. More specifically, the present invention relates to a system which is configured to provide that consumer devices that act as either USB host or USB device can connect to a vehicle's embedded USB host that does not have On the Go ("OTG") capability through an embedded USB hub in the vehicle.

Historically, mobile consumer devices such as media players, smart phones, tablets and the like have relied on connections to other devices, such as laptop or desktop personal computers ("PC's") to acquire content, exchange data, and charge the device's internal battery. For many years now, that has been accomplished through USB ports on each device. The use of USB technology is suitable for such needs since it is commonly available, familiar to the end user, cost effective and ubiquitous. USB protocols require a point-to-point connection in which one end is the USB Host or master, and the other end is a USB Device or slave. In this way, the flow of messages between the two devices is managed and controlled, whereby the USB Device responds to messages initiated by the USB Host. Historically, PC's have provided USB Host ports for connection to simpler USB Devices such as printers, memory sticks, mobile phones, etc. The USB Host has a greater burden of software and hardware requirements than a USB Device, so it has made sense to designate the PC as the USB Host in such systems.

In vehicle systems that employ USB connections, the same concepts apply. In such systems, the vehicle is typically the USB Host. The USB Host function is often embedded into a component of the vehicle infotainment system, such as into the radio or other control module. Typically, multiple USB ports are strategically designed into the vehicle in locations convenient for the driver and passengers to connect their consumer devices. Once a consumer device is connected to one of the ports, the device begins charging and the vehicle infotainment system can access content on the consumer device. This is useful to enable features such as streaming music, video and other services the device may provide.

Such a system requires that each of the USB ports be physically connected to the vehicle's USB Host in a manner suitable for USB data flow. This is accomplished through electrical cabling which is embedded in the vehicle, and which connects each of the ports to the USB Host. Since there can be many USB ports in a vehicle, and each port requires a cable to connect the port to the USB Host, it is desirable to share cabling when possible to minimize cost and mass of the vehicle. This is accomplished through the use of USB Hubs. USB Hubs allow a single USB Host to connect to multiple USB Devices over a single cable between the USB Host and the USB Hub. As shown in FIGS. **1** and **2**, a single USB Hub can connect one USB Host to several USB Devices. Specifically, FIG. **1** illustrates a system wherein a self-powered USB Hub having a plurality of USB ports connects to a plurality of USB Devices (via a plurality of consumer-facing USB ports), while FIG. **2** illustrates a system wherein a self-powered USB Hub provides not only a plurality of USB ports which are in communication with a plurality of consumer-facing USB ports, but also a Secure Digital ("SD") card reader which is connected to a consumer-facing SD card connector. Other portions of FIGS. **1** and **2**, such as Power Management, are standard in the industry and self-explanatory upon viewing FIGS. **1** and **2**.

Furthermore, as shown in FIG. **3**, multiple USB Hubs can be tiered, such that USB Hubs connect to other USB Hubs. Specifically, FIG. **3** illustrates a vehicle system architecture that includes a central vehicle microcontroller (also referred to as the Head Unit or "HU"). Connected to the Head Unit are components or systems such as displays, the audio system, entertainment system and the driver controls. The Head Unit may be architected as a single module encompassing all functions or distributed such that various functions are managed by individual modules. The Head Unit includes a Root USB Hub which is typically connected to one or more downstream USB Hubs distributed throughout the vehicle. Each USB Hub has a plurality of downstream ports (at least one of which may be an SD reader or USB audio device), thereby effectively providing that each USB port in the vehicle has a connection to the USB Host or Head Unit. In FIG. **3**, for example, the Root Hub is embedded in the radio, and is connected to four (4) self-powered USB Hubs, wherein one is in the vehicle's center console, one is in the vehicle's center stack, and two are in the vehicle's rear seats.

Recently, mobile devices such as smart phones have gained in popularity. This is, in part, due to their usefulness as standalone computing devices. With advances in consumer electronic technology and increases in the speed of mobile networks, these devices are no longer reliant on being connected to PCs to access content. These smart mobile devices now have many of the same hardware resources, connectivity and software operating systems that only PCs had in past years. As has been the case with desktop PCs, accessories for these mobile devices have become available to aid in their ease of use. These accessories have included devices such as keyboards, mice, displays, touchscreen, audio systems, and other interface devices. These accessories commonly connect via a USB connection. By way of established convention in the consumer electronics market, these accessories are typically low cost and limited in USB capability to act only as a USB Device. To connect them to a smart phone, the smart phone must be the USB Host. Therefore, leading mobile device manufacturers and system designers have begun designing their mobile device products (i.e. smart phones, tablets, etc) to support both USB Host and USB Device roles. In other words, the phone may configure itself such that it can function as a USB Device when it needs to be, or as a USB Host when it needs to be. Recently, the system level design thinking has shifted towards viewing smart phones as the USB Host, and any device connecting thereto as the USB Device. Again, this is not surprising since this is exactly how laptops and PCs work today. Extending this trend into the future, it can be predicted that the smart phone will act

primarily as the USB Host, and will rarely or never act as a USB device. This presents some problems for automotive systems.

As explained previously, automotive systems have a USB Host and require USB Devices to connect to it. If a phone acts as a USB Host, then the system will not function since by USB convention, two USB Hosts cannot directly connect with each other. Automotive manufacturers desire compatibility with smart phones and are therefore motivated to adapt to this changing technology. A redesign of the USB architecture in the vehicle is thus necessary such that the vehicle can act either as the USB Host (when necessary to connect to USB Devices such as memory sticks, thumb drives, etc.) or USB Device (when necessary to connect to USB Hosts, such as a smart phone which demands to be USB Host rather than USB Device.

The USB organization has added a standard that addresses the need for devices to act as either USB Host or USB Device and as such can be considered a “dual role” USB controller. It is referred to in USB nomenclature as “On The Go” or “OTG” for short. Any device that meets the OTG standard can act as either USB Host or USB Device and can change roles dynamically. Therefore, one possible approach to modifying the vehicle USB architecture to support all use cases is to upgrade the vehicle’s USB Host to USB OTG. This solution addresses the issue but has some disadvantages. First, USB Hubs do not support OTG and can no longer be used in the system. Each consumer accessible USB port that supports OTG must have a dedicated wire link to a dedicated OTG controller in the Head Unit thus negating the wiring savings associated with use of USB Hubs. As a result several costly cables may need to be added to the vehicle’s electrical system. Second, there may not be enough OTG controllers available in the Head Unit to connect to each of the vehicle’s user accessible USB ports. This then forces the vehicle designer to choose a limited number of the many USB ports in the vehicle to support the OTG function and run dedicated USB cables to them. This can lead to user confusion and dissatisfaction since only certain consumer ports support the required functionality. Also, ports that support OTG may be co-located with other physically identical ports that do not. If the user chooses the wrong one, the applications they desire to run from the consumer device that requires USB Host mode won’t work.

Another possible solution is to implement custom USB hubs wherein the USB Hub is able to dynamically swap its upstream port with one it’s downstream ports when commanded to do so. System solutions built with this concept still require OTG controllers in the head unit but benefit from the fact that no additional wires need to be installed in the car. The existing USB cable between the USB OTG Host and the USB Hub can facilitate the necessary USB communications between the USB OTG controller in the Head Unit (HU) and a consumer device in USB Host (such as a smart phone). This solution also has some disadvantages however. For example, when the USB Hub is commanded to swap it’s upstream port with a downstream port, all other downstream ports of the USB Hubs lose their data connection with the Head Unit. While in this mode the Head Unit access to the other downstream ports of the hub cease. This may prevent use of certain vehicle system functions such as navigation or audio playback that may need consistent access to the other downstream ports of the hub to function. Furthermore, it requires the HU to have an available USB OTG port and a signaling path to control the hub upstream/downstream port configuration.

SUMMARY

An object of an embodiment of the present invention is to provide a system which is configured to enable a vehicle’s embedded USB Host system to connect to mobile devices through a USB Hub, regardless of whether the mobile devices are configured to act as USB Hosts or USB Devices, without the need to provide OTG or dual role controllers in the head unit and without the need to provide additional cabling in the vehicle. Preferably, no hardware changes are required to be made to the USB Host circuits in the HU.

An embodiment of the present invention provides a system which can be employed between a vehicle’s embedded USB Host and at least one, but preferably multiple, consumer facing USB ports provided in the vehicle for connection to consumer devices. The system is configured to recognize and control whether the consumer device is required to be connected to each USB port as a USB Host or as a USB Device. Further, the system is able to dynamically switch the device connection between USB Device mode and USB Host mode when desired. In the case where the consumer device is acting as a USB Device, signals are routed normally through a USB Hub to the Head Unit. In the case where the consumer device is acting as a USB Host, signals between the consumer device and the vehicle’s embedded USB Host are routed and processed through a USB Host to Host Bridge which is connected to the USB Hub, thereby rendering the consumer device compatible with the vehicle’s embedded USB Host.

The present invention is capable of being implemented in several different embodiments. For example, an embodiment of the present invention comprises a USB Hub Module having a USB Hub, USB Bridge, and USB routing switches implemented as discrete devices. The USB Hub upstream port is configured to be connected to a vehicle’s embedded USB Host (such as a USB Host in a Head Unit). The USB Hub Module also includes a switching device (such as USB analog multiplexing switches for example) that is configured to route each consumer port to either the Bridge or the Hub. The USB Bridge is configured to effectively control the switching device. The USB Bridge is configured, based on signals from the Head Unit, whether the consumer device which is connected to the USB port is acting as USB Host or USB Device. In the case where the consumer device is acting as USB Host, the USB Bridge controls the switching device to route the USB port to the Bridge. The Bridge processes the signals from the consumer device and provides them to the USB Hub, thereby rendering the consumer device compatible with the vehicle’s embedded USB Host. In the case where the consumer device is acting as USB Device, the USB Bridge controls the switching device such that the switching device provides the signals to the USB Hub, effectively bypassing the Bridge.

Still another embodiment of the present invention provides that the USB routing logic, USB Bridge, and USB Hub are integrated in a single combination USB Hub/USB Bridge Integrated Circuit (IC).

Still other embodiments are entirely possible, some of which are described and illustrated herein. For example, the concept can be extended to include additional embedded USB Device functions such as USB HID and USB Audio. Further it is also envisioned that all consumer facing USB ports of the Hub Module can emulate or otherwise support dual role USB capability provided that each downstream port has a Bridge to support USB Host mode for the connected device and a direct connection to the USB Hub to

support USB Device mode. In all cases, compliance to USB protocols and architectures is preferably maintained.

BRIEF DESCRIPTION OF THE DRAWINGS

The organization and manner of the structure and operation of the invention, together with further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawings wherein like reference numerals identify like elements in which:

FIG. **1** illustrates a system wherein a multiple port self-powered USB Hub functions to connect a single USB Host to a plurality of USB ports;

FIG. **2** illustrates a system wherein a self-powered USB Hub provides not only a plurality of USB ports, but also a Secure Digital ("SD") card reader;

FIG. **3** illustrates a vehicle infotainment system structure wherein multiple USB Hubs are connected together or tiered, such that USB Hubs feed other USB Hubs;

FIG. **4** illustrates a system which is in accordance with an embodiment of the present invention, wherein a USB Hub, USB Bridge and a switching device are provided as discrete components;

FIG. **5** illustrates a system which is in accordance with an alternative embodiment of the present invention, wherein USB routing/switching logic and a USB Bridge are integrated with a USB Hub in a combination USB Hub/USB Bridge Integrated Circuit (IC);

FIG. **6** illustrates the different components of the combination USB Hub/Bridge IC shown in FIG. **5**;

FIG. **7** illustrates one possible endpoint configuration of the USB Bridge shown in FIGS. **5** and **6**; and

FIG. **8** illustrates an example implementation of a Head Unit Software Architecture.

DESCRIPTION OF ILLUSTRATED EMBODIMENTS

While this invention may be susceptible to embodiment in different forms, there are specific embodiments shown in the drawings and will be described herein in detail, with the understanding that the present disclosure is to be considered an exemplification of the principles of the invention, and is not intended to limit the invention to that as illustrated.

FIG. **4** illustrates a system which is in accordance with an embodiment of the present invention. The system is configured to effectively render a vehicle's embedded USB Host compatible with consumer devices which are configured to also act as USB Host or USB Device. The system is in the form of a self-powered USB Hub Module having a USB, a USB Bridge, and a switching device implemented as discrete devices. The USB Hub is preferably provided in the form of an integrated circuit (IC), and is configured (via an upstream USB port) connected to a vehicle's embedded USB Host (such as a USB Host in a Head Unit) via vehicle internal wiring, such as, in one embodiment, via a single USB data cable between the Head Unit and USB Hub. The USB Hub also includes a plurality of downstream USB ports, at least one of which is connected to a USB Bridge (which also is preferably provided in the form of an integrated circuit (IC)). At least one downstream USB port of the USB Hub is connected to a switching device (such as USB analog multiplexing switches, for example). The switching device is configured to be connected to at least one USB port in the vehicle for connection to a consumer device. The USB Bridge is configured to effectively control the

switching device although other control mechanisms are envisioned. The USB Hub Module is configured such that signals received from at least one USB port are received by the switching device, and the switching device routes the signals to the USB Bridge or the USB Hub. In the case where the consumer device is acting as USB Host, the USB Bridge processes the USB packets from the consumer port and provides them to the USB Hub, thereby rendering the consumer device compatible with the vehicle's embedded USB Host. In the case where the consumer device is acting as USB Device, the USB Bridge controls the switching device such that the switching device provides the USB signaling directly to the USB Hub, bypassing the Bridge.

As shown in FIG. **4**, the system also includes Power Management structure, as well as some other conventional structure not specifically shown in FIG. **4**, but which would be readily assumed to be present by one having ordinary skill in the art.

In use, the Head Unit controls the switching device via the USB Bridge hardware or any other convenient means of control. The HU software application may choose to enable, for example, a phone on any one of the consumer USB ports, by requesting, commanding or otherwise knowing the phone is required to be in USB Host mode and commanding the routing of the specific USB port the phone is attached to the USB Bridge. Once routed to the USB Bridge, the phone will detect a USB Device is connected and the phone will begin the standard USB enumeration sequence. The detection and enumeration processes are defined by USB standards and not explained here in detail. However, for purposes of describing the operation of the invention, a general understanding is provided herein. The enumeration process follows a strict sequence of USB descriptor requests from the USB Host and USB descriptor responses from the USB Device that allow the Host to determine the capabilities and functions of the Device and configure the USB Device for operation. Once the complete set of device descriptors are known the USB Host will then load the appropriate USB driver(s) and applications to support in the functionality that the USB Device provides. In the scope of this invention it is envisioned that the responses to the descriptor requests made by the phone (USB Host) are either answered locally by the Bridge or preferably, the requests are forwarded through the Bridge to the Head Unit where its device drivers process the request and return the response. The descriptor responses from the device driver are conveyed to the USB Bridge, which then, in turn, passes them to the phone. By passing descriptor request to the Head Unit drivers and returning the responses from the Head Unit drivers back to the consumer device, the Bridge appears as a transparent component in the USB system architecture. The system capabilities are controlled by the Head Unit and the system remains flexible without need for changes to the Bridge firmware or hardware when the system designer requires changes to the descriptor responses. Once the consumer device completes the enumeration process, the Head Unit's USB functional capabilities are known to the consumer device and the consumer device may enable use of those functions over USB communication. At this point, the consumer device or the Head Unit may begin activating any number of supported services such as data connections, streaming audio and streaming video to and from the vehicle via the USB Bridge.

Another embodiment of the present invention can be provided, wherein the bridge is configured to act as an OTG port thus negating the need for switches and/or routing logic. In this case there would exist one Bridge functional block for

each downstream port. This embodiment would effectively be a more generalized case of the example illustrated in FIG. **4**. FIG. **4** shows just one Bridge that any one of the consumer USB ports can be routed to. With just one bridge, only one consumer USB port can be connected to a USB host at a time. However, if each downstream port of the Hub has a dedicated Bridge, then multiple consumer ports can support connection to USB Host devices at the same time. Thus, any consumer port can be in either USB Host or USB Device mode at any time independently of the others.

FIG. **5** illustrates an alternative embodiment wherein the switching device comprises USB routing logic, and both the USB routing logic and the USB Bridge are integrated with the USB Hub in a combination USB Hub/USB Bridge Integrated Circuit (IC). This configuration has cost and size advantages over building it with discrete components connected together on a printed circuit board.

FIG. **6** illustrates the internal components of the USB Hub/USB Bridge Integrated Circuit (IC) shown in FIG. **5**. As shown, preferably the components of the USB Bridge include a bridge controller as well as endpoint buffers. While the exact configuration of endpoints is effectively up to the system designer to choose for a particular need, a specific example of one possible endpoint configuration is shown in FIG. **7**; however, many others are possible.

As shown in FIG. **7**, the endpoints of the Bridge may be designed to support multiple pipes of Bulk USB data connections between the Host A (Head Unit) and Host B (consumer device). In the Bridge, the IN endpoints of Device A are connected to the OUT endpoints of Device B and the OUT endpoints of Device A are connected to the IN endpoints of Device B. The design of the Bridge may be such that the data flow between the endpoints may be direct or buffered. For example, in the case of direct connection, once a USB packet is received from Host A on a Device A OUT endpoint, the internal logic of the Bridge moves to packet to the Device B IN endpoint if it is available. If Device B IN endpoint is full or otherwise not available then subsequent attempts of Host A to send more packets to Device A in the Bridge will be rejected until such time that the Device B IN endpoint is clear and the contents of the Device A OUT buffer is moved to it. Alternatively, there may exist a local buffer in the Bridge between the endpoints of Device A and B. For example, packets received on an OUT endpoint of Device A are placed in a local memory device for temporary storage until Device B IN endpoint is ready for them. The OUT endpoints are thus capable of receiving multiple packets from the Host until the buffer is full. Likewise the IN endpoints may, at times, transmit multiple packets until the buffer is empty. Such buffers are not required, but are envisioned, to improve system throughput performance in certain circumstances where one of the USB Hosts is occasionally busy and not keeping up with USB transactions at the same rate as the other USB Host. Regardless of the buffer configuration, the Bridge hardware has IN and OUT endpoints on Device A mapped to OUT and IN endpoints respectively on Device B, thus forming a bidirectional bridge that passes USB traffic between two USB Hosts with bandwidth sufficient to support the application requirements of the system.

Also shown in FIG. **7**, Device A and Device B provide a bidirectional Control endpoint connected to their respective USB Hosts. Control endpoints are required per USB standard to support USB defined control messages between the Host and Device both during and after the enumeration sequence. Optionally, USB endpoints may also be utilized per USB standard to employ messages intended to control

user defined custom device specific behavior, referred to as Vendor Specific messages. As can be seen in FIG. **7**, the Control endpoints are mapped to the Bridge Controller (BC). The BC logic may be implemented in hardware or preferably software. The BC provides the capability to send, receive and process USB standard Control endpoint messages as well as vendor specific messages essential to the control and operation of the Bridge. At system startup, the A Host requests and receives descriptors from the BC via the Control endpoint. Once complete, Host A then loads the Bridge Driver in its software stack and configures the custom Bridge hardware for operation. Host A can then control the functions of the Bridge, such as USB switch routing control. The system is now ready to accept connection with USB Host mode consumer devices on the B Device of the Bridge. When such a connection is made, the BC will notify the Bridge Driver in Host A by sending a message on the control endpoint to Host A. Further, Host B will begin sending descriptor requests on the control endpoint to Device B in Bridge. The BC receives theses requests, encapsulates them with information that identifies them as descriptor requests from Host B and passes them to the Bridge Driver on Host using the control endpoint. Host A Bridge Driver receives these requests, identifies them as descriptor requests and passes the requests on to other software components in Host A system and waits for the descriptor responses. The descriptor responses are encapsulated by the Bridge driver to indicate they are descriptor responses that are to be forwarded to Host B. The response is then sent to the BC via the control endpoint. The BC receives them, identifies them as descriptor responses that should be forwarded to Device B and places them on the control endpoint for Device B. This process of receiving and forwarding messages back and forth between the two hosts continues until the enumeration process is complete with Host B. From that point on the two hosts may begin to use the IN and OUT endpoints to transfer application data and services over the bulk endpoints.

FIG. **8** illustrates one possible configuration of the system architecture including software components in the Head Unit interfacing with the Bridge/Hub. There are multiple ways that the operating system and software architecture can be constructed to support the functions of the USB Bridge/Hub. In FIG. **8**, a typical Linux implementation is shown including the Bridge/Hub Module and the Head Unit. The system design utilizes standard Linux Kernel components and configurations and should be familiar to those skilled in the art. The Head Unit USB Host Controller hardware is driven by the Host Controller Driver. The Host Controller Driver is connected to the USB Core. The USB Core connects the HCD with the standard USB Linux Device Drivers and the custom Bridge Driver. The Bridge Driver is configured to optionally connect directly to the User Space Application software or to the USB Gadget Driver depending on system architecture. The custom Bridge Driver plays a dual role of both controlling the functions of the Bridge hardware as well as providing a data path between the gadget device drivers and applications running on the Head Unit. The architecture illustrated is capable of handling both the operation and data paths associated with the Bridge and the Hub at the same time, thus allowing concurrent operation of consumer devices operating in USB Device mode with consumer devices operating in USB Host mode. In one embodiment, the Hub/Bridge supports simultaneous active USB data connections between the Head Unit and multiple consumer devices, at least one of which being in host mode while the others are in device mode. In another embodiment,

the Hub/Bridge supports simultaneous active USB data connections between the Head Unit and some combination of embedded and consumer USB devices along with at least one device being in host mode. While it is understood that the software functions of the head unit are essential to building a complete system, the designs of which can vary significantly and this example is provided only as a means of demonstrating one way to utilize the functionality of the present invention.

What is claimed is:

1. A system disposed within a vehicle, comprising:

an embedded Universal Serial Bus (USB) Host system;

a USB Hub having a plurality of USB Ports and interconnected to the embedded USB Host system, said USB Hub configured to simultaneously broadcast data from the embedded USB Host system to each USB Port in the plurality of USB Ports and to transmit data from each USB Port to the embedded USB Host system;

a USB Bridge interconnected to the USB Hub and configured to connect the embedded USB Host system to a second USB Host; and

a USB routing switch interconnected to the USB Bridge, the USB Hub, and the plurality of USB Ports, wherein the USB routing switch is configured to connect a first USB Port of the plurality of USB Ports to the USB Hub through the USB Bridge when a consumer device connected to the USB Port is the second USB Host and is configured to initiate bidirectional communication with the embedded USB Host, and wherein the USB routing switch is configured to connect the first USB Port directly to the USB Hub when the consumer device connected to the first USB Port is configured to only respond to communication from the embedded USB Host, thereby rendering the consumer device compatible with the embedded USB Host system.

2. A system as recited in claim **1**, wherein the USB routing switch is configured to connect the first USB Port to the USB Hub through the USB Bridge when a first consumer device connected to the first USB Port is the second USB Host, and wherein the USB routing switch is configured to simultaneously connect a second USB Port of the plurality of USB Ports directly to the USB Hub when a second consumer device connected to the second USB Port is the USB Device, thereby rendering the first and second consumer devices compatible to function simultaneously with the embedded USB Host system.

3. A system as recited in claim **1**, wherein the system is configured to recognize whether the consumer device connected to the USB Port is the second USB Host or the USB Device and control the USB routing switch accordingly.

4. A system as recited in claim **1**, wherein the USB Hub, the USB Bridge, and the USB routing switch system are disposed within a USB Hub Module.

5. A system as recited in claim **1**, wherein the system further comprises an infotainment system containing the embedded USB Host system.

6. A system as recited in claim **4**, wherein the system is configured to dynamically switch operation of USB Ports connected to the USB Hub Module between USB Device mode and USB Host mode.

7. A system as recited in claim **4**, wherein the USB Hub Module is connected to the embedded USB Host system and the plurality of USB Ports connected to a plurality of consumer devices.

8. A system as recited in claim **7**, wherein the USB routing switch is configured to connect each consumer device of the plurality of consumer devices to either the USB Bridge or the USB Hub based on whether each consumer device attached to each USB Port in the plurality of USB Ports is the USB Host or the USB Device.

9. A system as recited in claim **1**, wherein the USB routing switch comprises a plurality of USB analog multiplexing switches.

10. A system as recited in claim **1**, wherein the USB Bridge is configured to control the USB routing switch.

11. A system as recited in claim **1**, wherein the USB routing switch comprises digital routing logic.

12. A system as recited in claim **1**, wherein the USB Bridge comprises a bridge controller as well as endpoint buffers.

13. A system as recited in claim **12**, wherein the endpoint buffers are configured to support a USB data connection pipe between an infotainment system and the consumer device.

14. A system as recited in claim **1**, wherein the system further comprises an infotainment system with the embedded USB Host which is electrically connected to the USB Hub via a single USB data connection.

15. A system as recited in claim **1**, wherein the system further comprises an infotainment system, wherein the system is configured to support simultaneous active USB data connections between the infotainment system and multiple consumer devices, at least one of which is the second USB Host while others are USB Devices.

16. A system as recited in claim **1**, wherein the system further comprises an infotainment system, wherein the system is configured to support simultaneous active USB data connections between the infotainment system and some combination of embedded devices and consumer devices that are USB Devices along with at least one that is the second USB Host.

17. A system as recited in claim **11**, wherein the USB Hub, the USB Bridge, and the USB routing switch system are integrated in an Integrated Circuit (IC).

* * * * *

EXHIBIT D

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(12) **United States Patent**
Voto et al.

(10) **Patent No.: US 10,545,899 B2**
(45) **Date of Patent: *Jan. 28, 2020**

(54) **FLEXIBLE MOBILE DEVICE CONNECTIVITY TO AUTOMOTIVE SYSTEMS WITH USB HUBS**

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(73) Assignee: **Aptiv Technologies Limited** (BB)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 316 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **15/441,775**

(22) Filed: **Feb. 24, 2017**

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(51) **Int. Cl.**

G06F 13/40 (2006.01)
G06F 13/38 (2006.01)
G06F 13/42 (2006.01)

(52) **U.S. Cl.**

CPC ***G06F 13/385*** (2013.01); ***G06F 13/4022*** (2013.01); ***G06F 13/4045*** (2013.01);
(Continued)

(58) **Field of Classification Search**

CPC . G06F 13/4022; G06F 13/4045; G06F 13/385
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,073,188 A	6/2000	Fleming
6,732,219 B1	5/2004	Broyles

(Continued)

FOREIGN PATENT DOCUMENTS

JP	2003256351 A	9/2003
TW	470887 B	1/2002

(Continued)

OTHER PUBLICATIONS

"Universal Serial Bus Specification Revision 2.0", Universal Serial Bus Specification No. Rev. 2.0, Apr. 27, 2000.

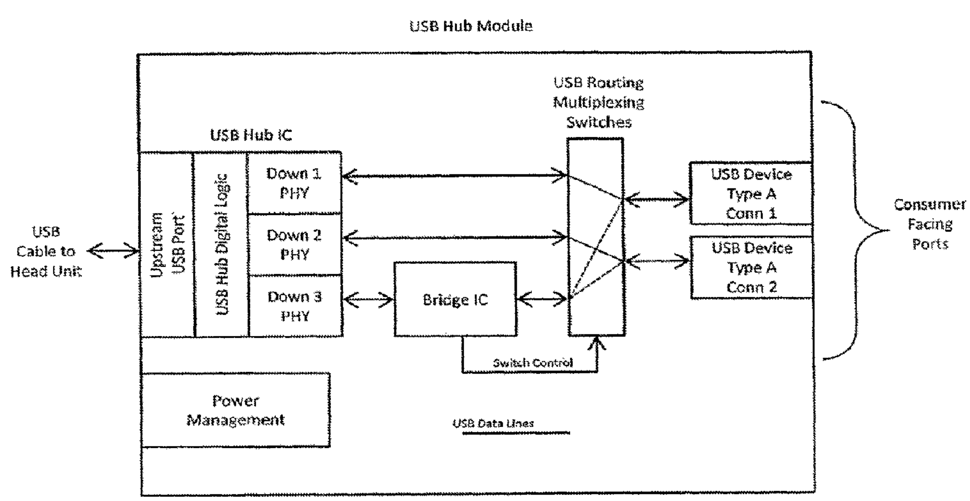
(Continued)

Primary Examiner — Ernest Unelus
(74) *Attorney, Agent, or Firm* — Robert J. Myers

(57) **ABSTRACT**

A method to enable a vehicle's embedded USB Host system to connect to multiple mobile devices through a USB Hub, regardless of whether the mobile devices are configured to act as USB Hosts or USB Devices, without OTG controllers or additional vehicle wiring, or inhibiting the functionality of any consumer devices connected to the same USB Hub. Preferably, the method is configured to provide that no additional cabling is required, and no hardware changes are required to be made to the HU. The method can be employed between a vehicle's embedded USB Host, USB Hub and at least one consumer accessible USB port. In the case where the consumer device is acting as a USB Host, signals between the consumer device and the vehicle's embedded USB Host are processed through a USB bridge, thereby rendering the consumer device compatible with the vehicle's embedded USB Host.

6 Claims, 8 Drawing Sheets



Related U.S. Application Data

continuation of application No. 14/487,947, filed on Sep. 16, 2014, now Pat. No. 9,460,037.

(60) Provisional application No. 61/882,915, filed on Sep. 26, 2013.

(52) **U.S. Cl.**
CPC .. ***G06F 13/4282*** (2013.01); *G06F 2213/0042* (2013.01); *G06F 2213/3812* (2013.01); *G06F 2213/4004* (2013.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,934,793	B2	8/2005	Ying et al.
6,957,287	B2	10/2005	Lou et al.
7,130,656	B2	10/2006	Okagaki et al.
7,280,802	B2	10/2007	Grady
7,478,191	B2	1/2009	Wurzburg et al.
7,502,878	B1 *	3/2009	Wright G06F 13/4022 710/37
7,523,243	B2	4/2009	Bohm et al.
7,627,708	B2	12/2009	Bohm et al.
8,447,598	B2	5/2013	Chutorash et al.
8,447,890	B1	5/2013	LeTourneur et al.
2003/0167345	A1	9/2003	Knight et al.
2004/0019732	A1	1/2004	Overtoom et al.
2004/0088449	A1	5/2004	Sakaki
2004/0243755	A1	12/2004	Lee et al.
2006/0056401	A1	3/2006	Bohm et al.
2006/0206650	A1	9/2006	Chang
2007/0067553	A1	3/2007	Chang
2007/0086724	A1	4/2007	Grady et al.
2007/0156293	A1	7/2007	Kellzi et al.
2007/0255885	A1	11/2007	Bohm et al.
2008/0005262	A1	1/2008	Wurzburg et al.
2009/0117890	A1	5/2009	Jacobsen et al.
2011/0054721	A1	3/2011	Goodrich et al.
2011/0124300	A1	5/2011	Sinai
2012/0134506	A1	5/2012	DeBiasio et al.
2012/0191811	A1	7/2012	Ng et al.
2012/0290859	A1	11/2012	Saladin et al.
2013/0053003	A1	2/2013	King, II
2013/0106750	A1	5/2013	Kurosawa
2015/0089092	A1	3/2015	Voto et al.

FOREIGN PATENT DOCUMENTS

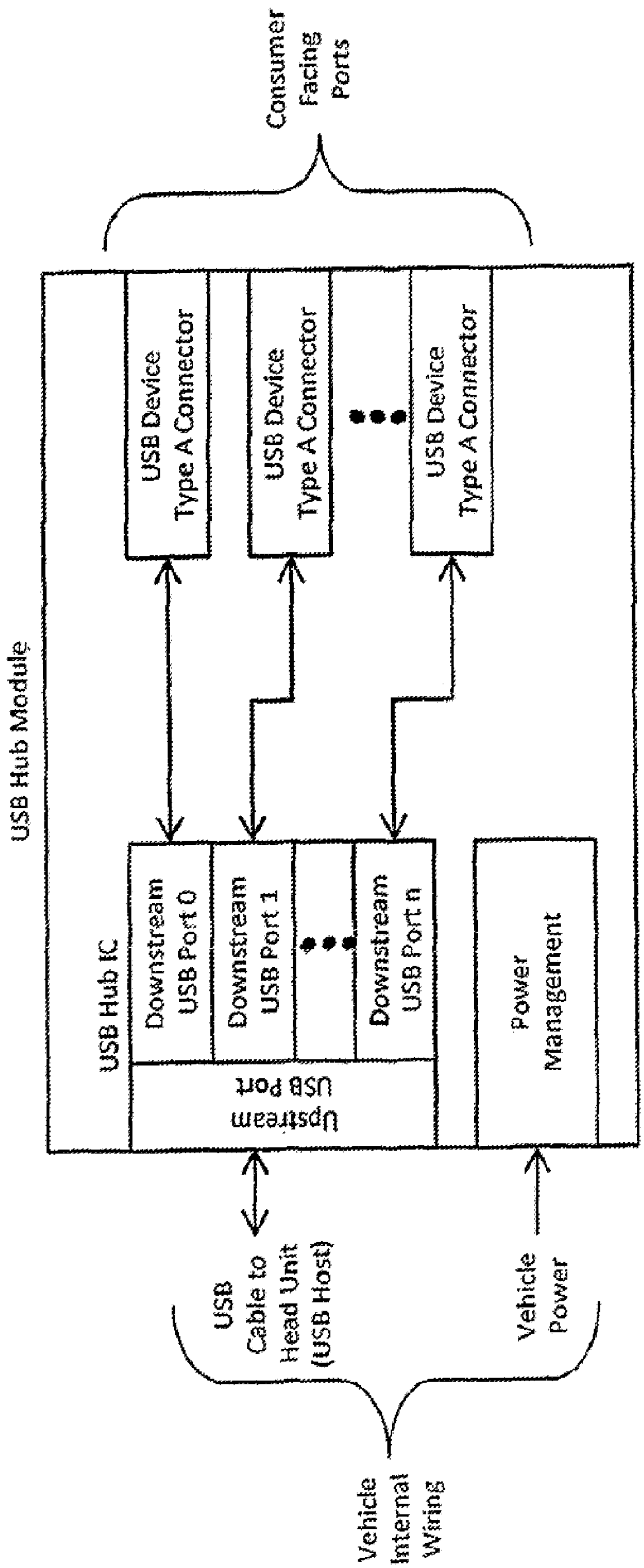
WO	2004/012090	A1	2/2004
WO	2007147114	A2	12/2007
WO	2015081448	A1	6/2015

OTHER PUBLICATIONS

USB Implementers Forum et al: "USB Power 3 Delivery Specification Revision 3.0, Version 1.0a", Mar. 25, 2016.
"FFI Rapport—A Study of Computer Interfaces for Soldier Systems", Lars Erik Olsen & Joakin Flathagen, Norwegian Defence Research Establishment, Oct. 10, 2005.
"USB 2.0 Autoswitch User's Manual", Lindy Electronics Limited & Lindy-Elektronic GMBH, Sep. 2002.
"APC USB 2.0 Host Controller—Device Driver Download", http://www.liutilities.com/devicedriver/apcusb20hostcontroller/, Jul. 2002.
"Peripheral-Sharing Hardware Suits Education's Needs to a 'T'", Terian Tyre, T H E Journal (Technological Horizons in Education), Oct. 1988.
European Search Report for Application No. 18195496, European Patent Office, dated Mar. 19, 2019.

* cited by examiner

Figure 1


Consumer Facing Ports
USB Device Type A Connector
USB Device Type A Connector
USB Device Type A Connector
USB Hub Module
USB Hub IC
Downstream USB Port 0
Downstream USB Port 1
Downstream USB Port n
Upstream USB Port
Power Management
USB Cable to Head Unit (USB Host)
Vehicle Power
Vehicle Internal Wiring

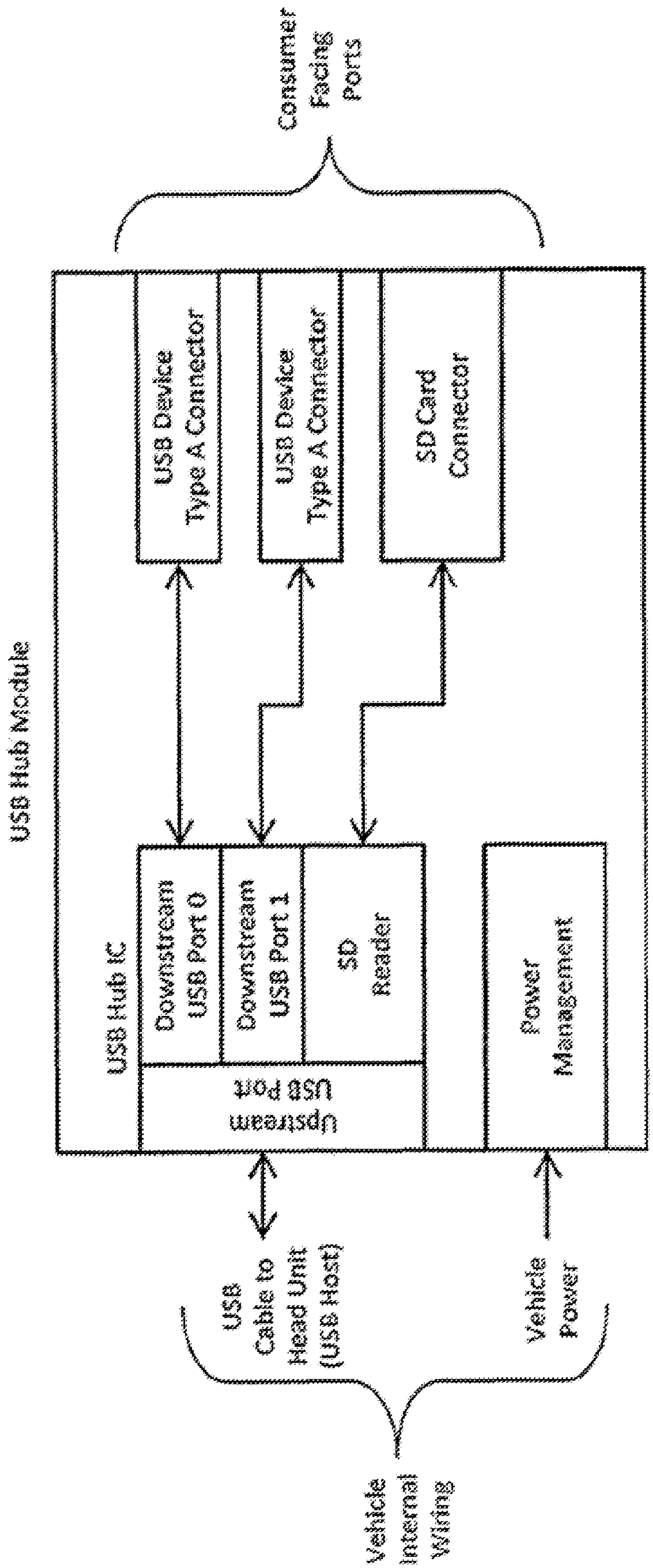
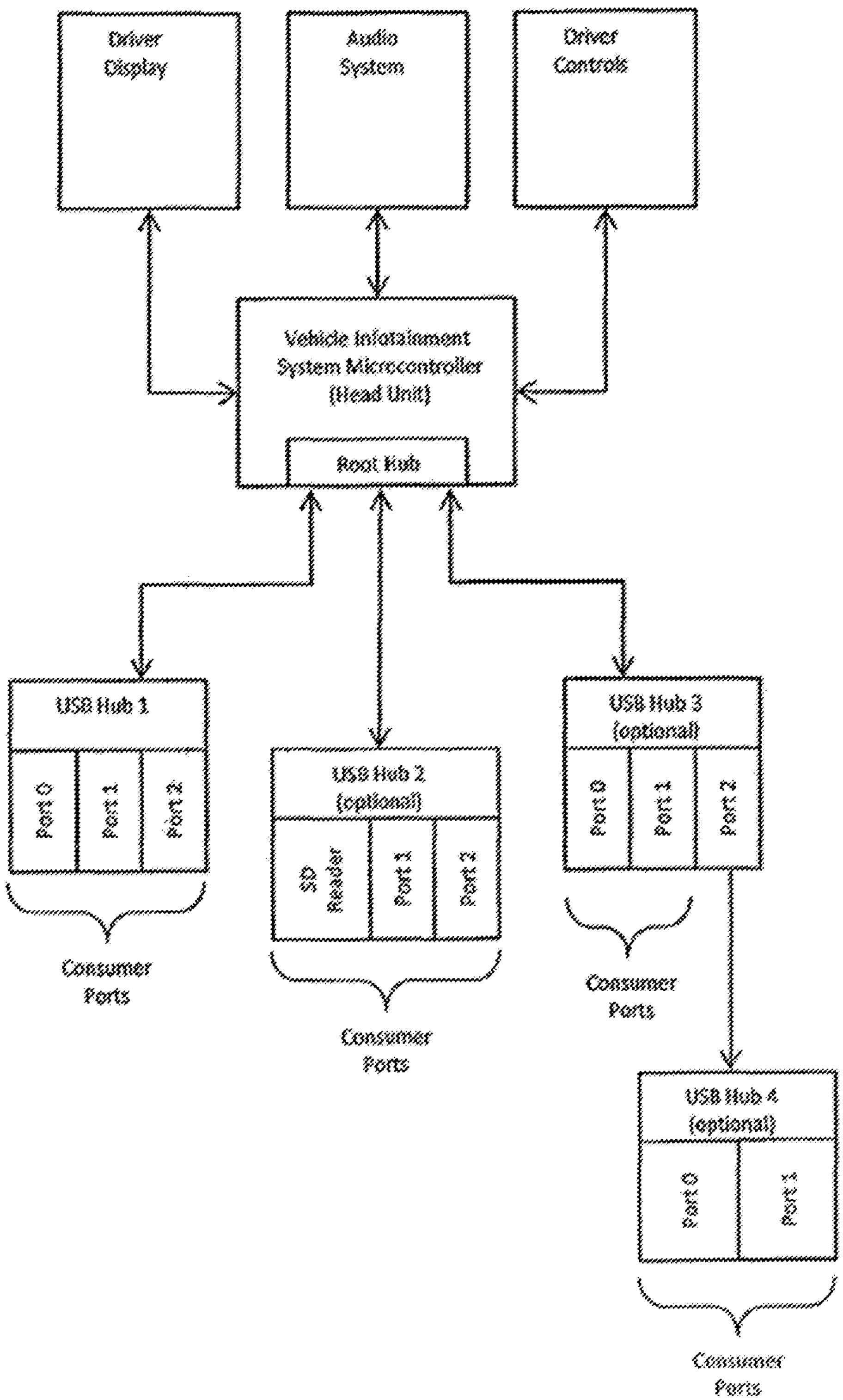

Consumer Facing Ports
USB Hub Module
USB Device Type A Connector
USB Device Type A Connector
SD Card Connector
USB Hub IC
Downstream USB Port 0
Downstream USB Port 1
SD Reader
Upstream USB Port
Power Management
USB Cable to Head Unit (USB Host)
Vehicle Power
Vehicle Internal Wiring

Figure 2

Figure 3



Driver Display
Audio System
Driver Controls
Vehicle Infotainment System Microcontroller (Head Unit)
Root Hub
USB Hub 1
Port 0
Port 1
Port 2
Consumer Ports
USB Hub 2 (optional)
SD Reader
Port 1
Port 2
Consumer Ports
USB Hub 3 (optional)
Port 0
Port 1
Port 2
Consumer Ports
USB Hub 4 (optional)
Port 0
Port 1
Consumer Ports

Figure 4

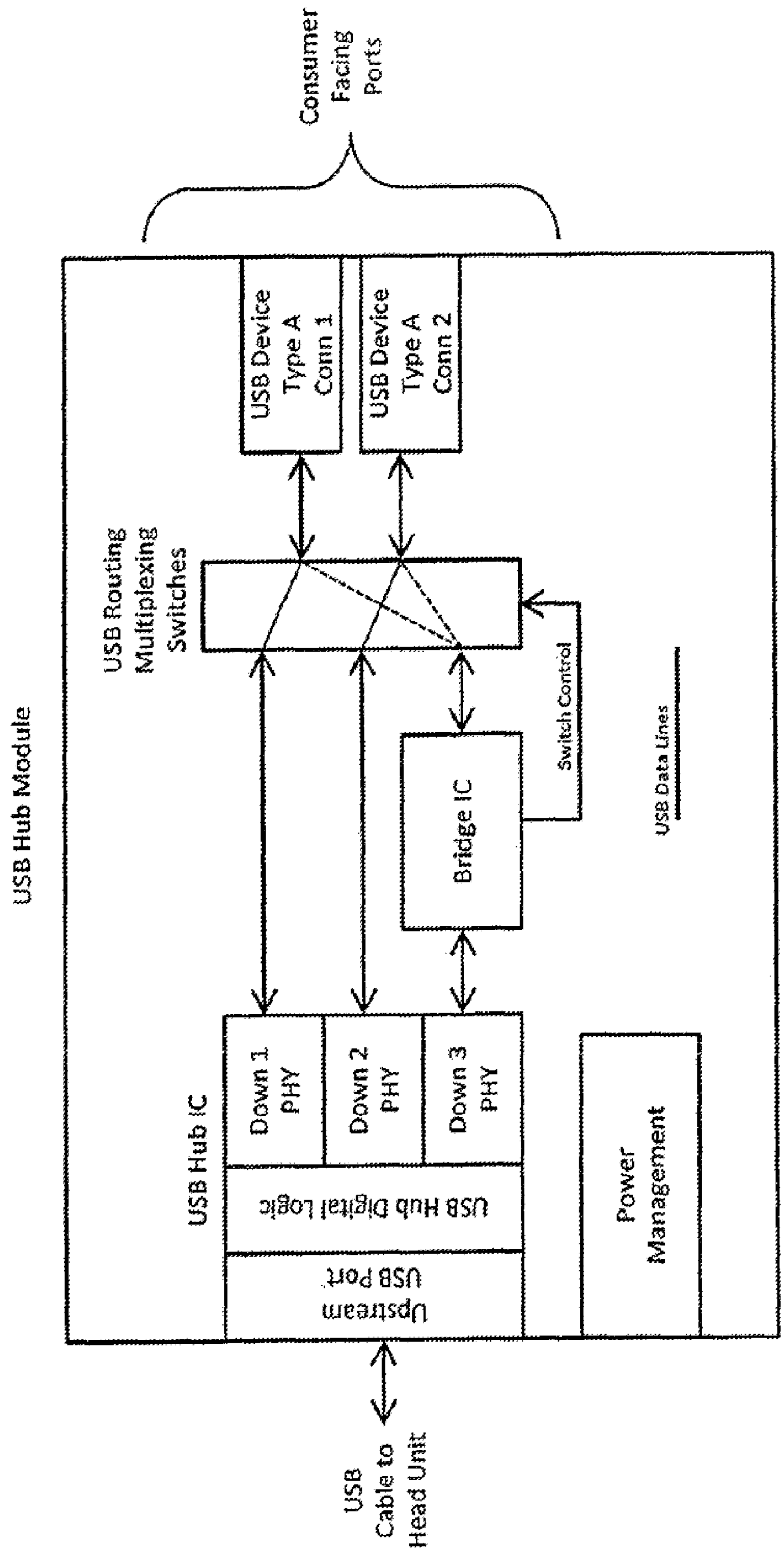

Consumer Facing Ports
USB Hub Module
USB Device Type A Conn 1
USB Device Type A Conn 2
USB Routing Multiplexing Switches
Switch Control
Bridge IC
USB Data Lines
USB Hub IC
Down 1 PHY
Down 2 PHY
Down 3 PHY
USB Hub Digital Logic
Upstream USB Port
Power Management
USB Cable to Head Unit

Figure 5

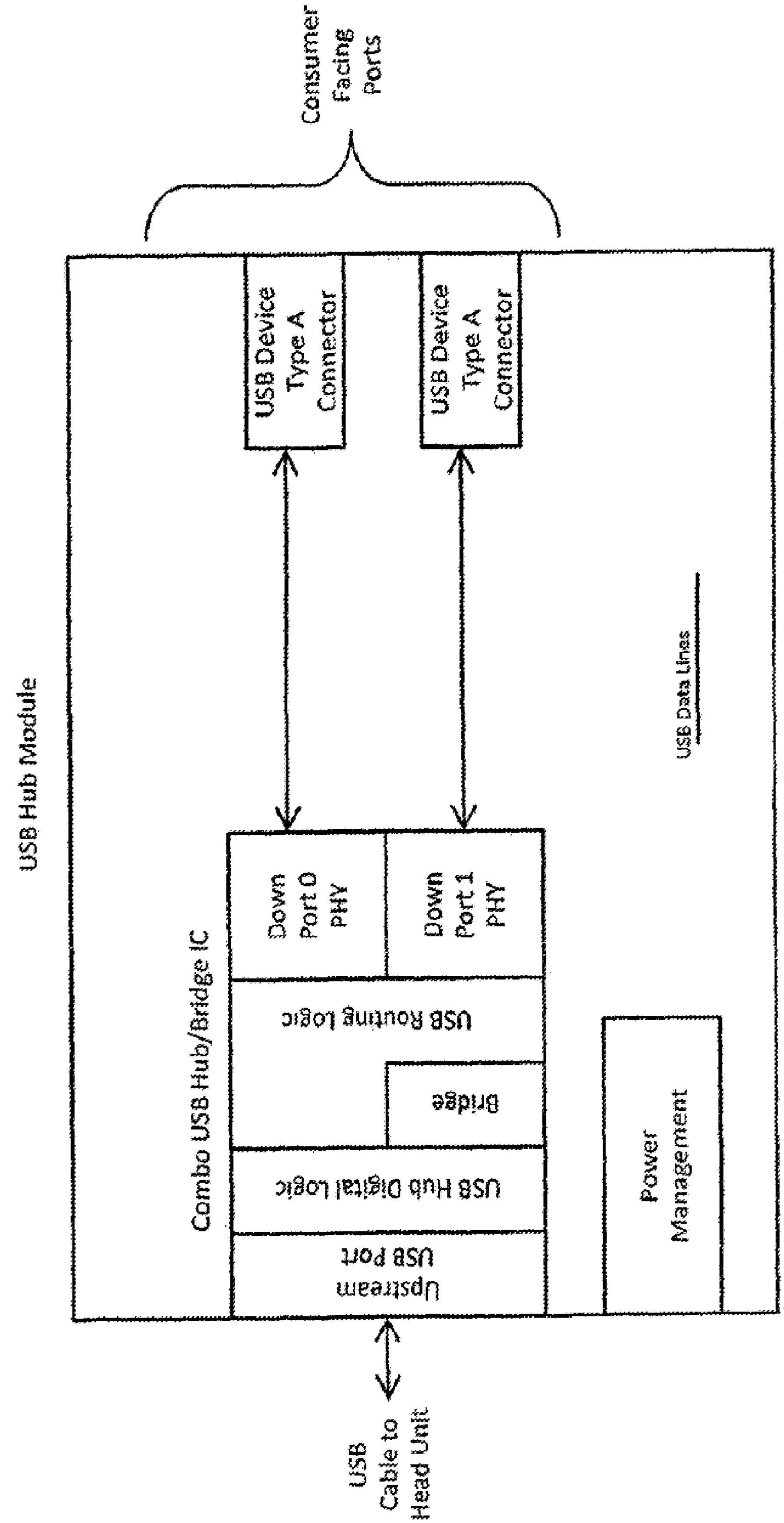

Consumer Facing Ports
USB Hub Module
USB Device Type A Connector
USB Device Type A Connector
Combo USB Hub/Bridge IC
Down Port 0 PHY
Down Port 1 PHY
USB Routing Logic
Bridge
USB Hub Digital Logic
Upstream USB Port
Power Management
USB Data Lines
USB Cable to Head Unit

Figure 6

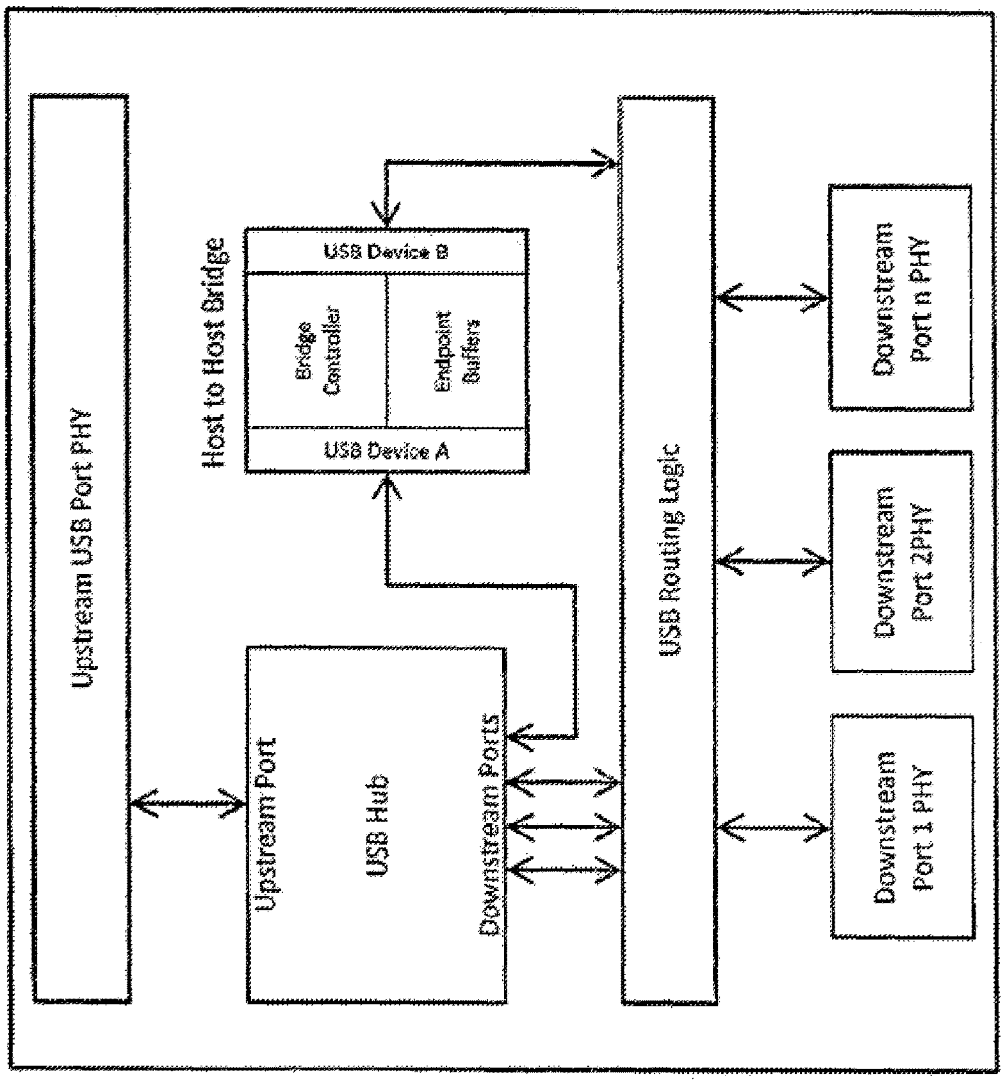

Upstream USB Port PHY
Host to Host Bridge
USB Device B
Bridge Controller
Endpoint Buffers
USB Device A
Upstream Port
USB Hub
Downstream Ports
USB Routing Logic
Downstream Port n PHY
Downstream Port 2PHY
Downstream Port 1 PHY

Figure 7

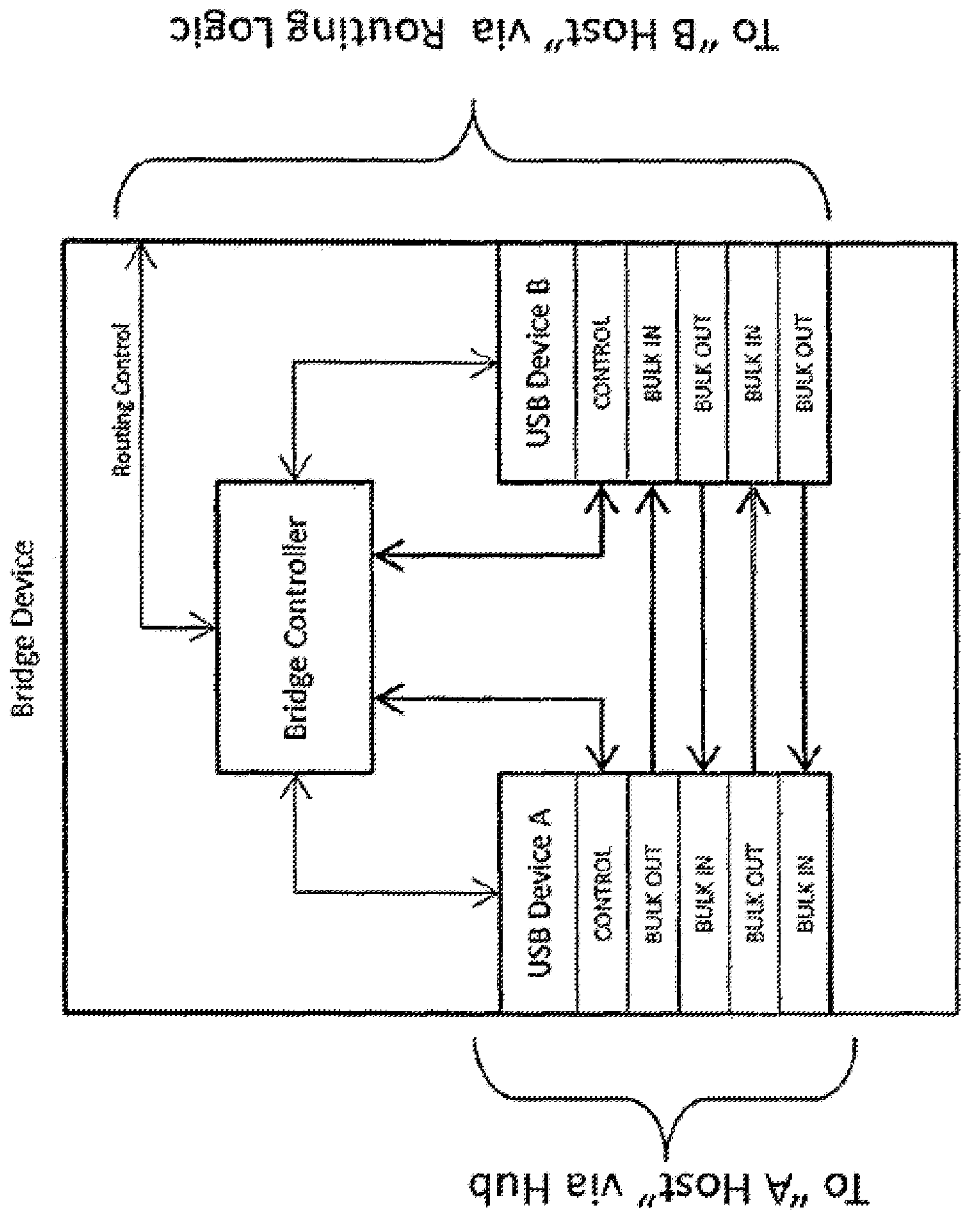
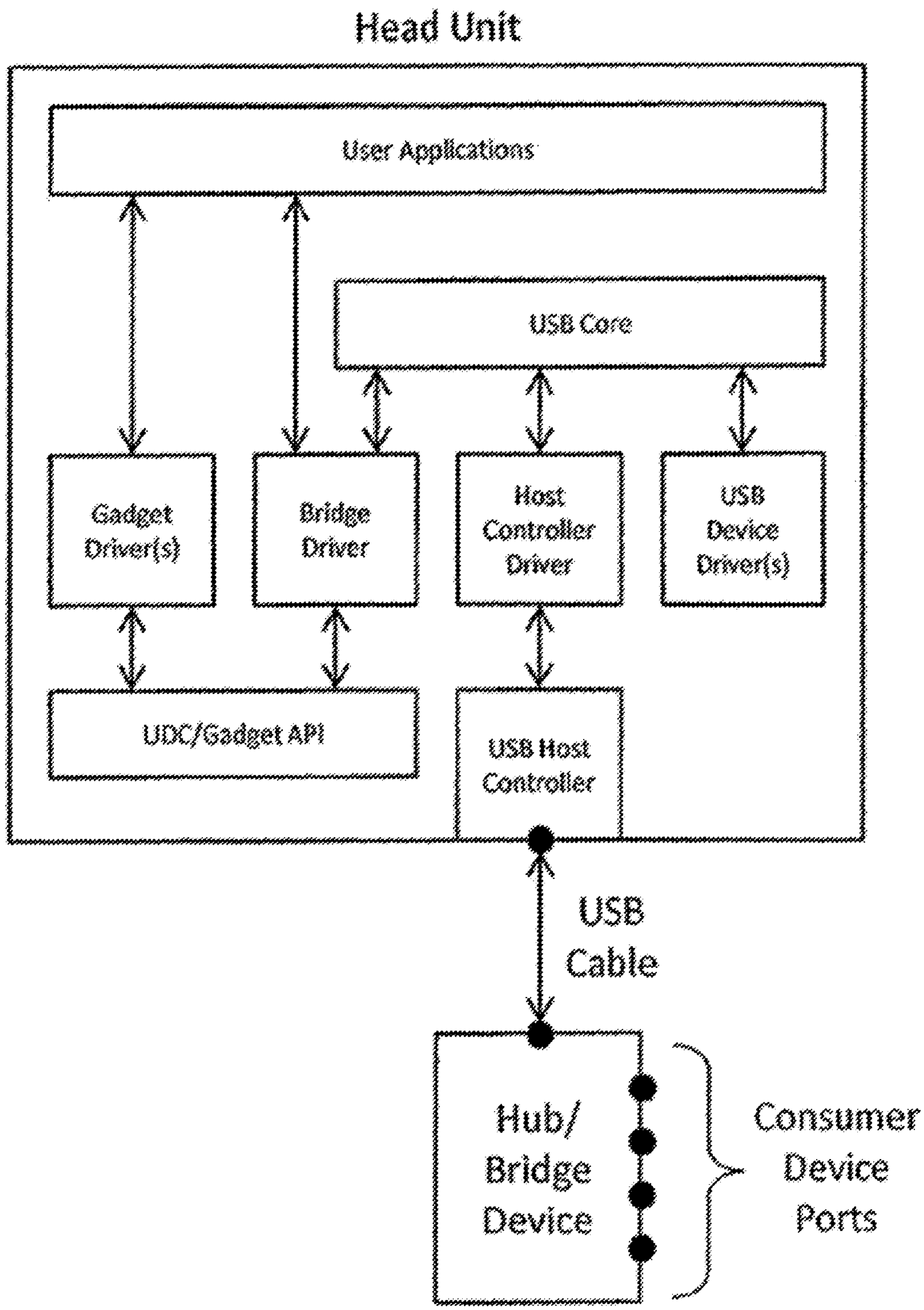

To "B Host" via Routing Logic
Bridge Device
Routing Control
Bridge Controller
USB Device B
CONTROL
BULK IN
BULK OUT
BULK IN
BULK OUT
USB Device A
CONTROL
BULK OUT
BULK IN
BULK OUT
BULK IN
To "A Host" via Hub

Figure 8



Head Unit
User Applications
USB Core
Gadget Driver(s)
Bridge Driver
Host Controller Driver
USB Device Driver(s)
UDC/Gadget API
USB Host Controller
USB Cable
Hub/ Bridge Device
Consumer Device Ports

FLEXIBLE MOBILE DEVICE CONNECTIVITY TO AUTOMOTIVE SYSTEMS WITH USB HUBS

RELATED APPLICATIONS

This application is a continuation application and claims benefit under 35 U.S.C. § 120 of U.S. patent application Ser. No. 15/268,728, filed Sep. 19, 2016, which is a continuation application that claimed benefit under 35 U.S.C. § 120 of U.S. patent application Ser. No. 14/487,947, now U.S. Pat. No. 9,460,037, filed on Sep. 16, 2014, which claimed benefit under 35 U.S.C. § 119(e) of U.S. Provisional Patent Application No. 61/882,915, filed on Sep. 26, 2013, the entire disclosure of each of which are hereby incorporated herein by reference.

BACKGROUND

The present invention generally relates to Universal Serial Bus ("USB") connectivity between, for example, mobile consumer devices and vehicle electronic systems. More specifically, the present invention relates to a system which is configured to provide that consumer devices that act as either USB host or USB device can connect to a vehicle's embedded USB host that does not have On the Go ("OTG") capability through an embedded USB hub in the vehicle.

Historically, mobile consumer devices such as media players, smart phones, tablets and the like have relied on connections to other devices, such as laptop or desktop personal computers ("PC's") to acquire content, exchange data, and charge the device's internal battery. For many years now, that has been accomplished through USB ports on each device. The use of USB technology is suitable for such needs since it is commonly available, familiar to the end user, cost effective and ubiquitous. USB protocols require a point-to-point connection in which one end is the USB Host or master, and the other end is a USB Device or slave. In this way, the flow of messages between the two devices is managed and controlled, whereby the USB Device responds to messages initiated by the USB Host. Historically, PC's have provided USB Host ports for connection to simpler USB Devices such as printers, memory sticks, mobile phones, etc. The USB Host has a greater burden of software and hardware requirements than a USB Device, so it has made sense to designate the PC as the USB Host in such systems.

In vehicle systems that employ USB connections, the same concepts apply. In such systems, the vehicle is typically the USB Host. The USB Host function is often embedded into a component of the vehicle infotainment system, such as into the radio or other control module. Typically, multiple USB ports are strategically designed into the vehicle in locations convenient for the driver and passengers to connect their consumer devices. Once a consumer device is connected to one of the ports, the device begins charging and the vehicle infotainment system can access content on the consumer device. This is useful to enable features such as streaming music, video and other services the device may provide.

Such a system requires that each of the USB ports be physically connected to the vehicle's USB Host in a manner suitable for USB data flow. This is accomplished through electrical cabling which is embedded in the vehicle, and which connects each of the ports to the USB Host. Since there can be many USB ports in a vehicle, and each port requires a cable to connect the port to the USB Host, it is

desirable to share cabling when possible to minimize cost and mass of the vehicle. This is accomplished through the use of USB Hubs. USB Hubs allow a single USB Host to connect to multiple USB Devices over a single cable between the USB Host and the USB Hub. As shown in FIGS. **1** and **2**, a single USB Hub can connect one USB Host to several USB Devices. Specifically, FIG. **1** illustrates a system wherein a self-powered USB Hub having a plurality of USB ports connects to a plurality of USB Devices (via a plurality of consumer-facing USB ports), while FIG. **2** illustrates a system wherein a self-powered USB Hub provides not only a plurality of USB ports which are in communication with a plurality of consumer-facing USB ports, but also a Secure Digital ("SD") card reader which is connected to a consumer-facing SD card connector. Other portions of FIGS. **1** and **2**, such as Power Management, are standard in the industry and self-explanatory upon viewing FIGS. **1** and **2**.

Furthermore, as shown in FIG. **3**, multiple USB Hubs can be tiered, such that USB Hubs connect to other USB Hubs. Specifically, FIG. **3** illustrates a vehicle system architecture that includes a central vehicle microcontroller (also referred to as the Head Unit or "HU"). Connected to the Head Unit are components or systems such as displays, the audio system, entertainment system and the driver controls. The Head Unit may be architected as a single module encompassing all functions or distributed such that various functions are managed by individual modules. The Head Unit includes a Root USB Hub which is typically connected to one or more downstream USB Hubs distributed throughout the vehicle. Each USB Hub has a plurality of downstream ports (at least one of which may be an SD reader or USB audio device), thereby effectively providing that each USB port in the vehicle has a connection to the USB Host or Head Unit. In FIG. **3**, for example, the Root Hub is embedded in the radio, and is connected to four (4) self-powered USB Hubs, wherein one is in the vehicle's center console, one is in the vehicle's center stack, and two are in the vehicle's rear seats.

Recently, mobile devices such as smart phones have gained in popularity. This is, in part, due to their usefulness as standalone computing devices. With advances in consumer electronic technology and increases in the speed of mobile networks, these devices are no longer reliant on being connected to PCs to access content. These smart mobile devices now have many of the same hardware resources, connectivity and software operating systems that only PCs had in past years. As has been the case with desktop PCs, accessories for these mobile devices have become available to aid in their ease of use. These accessories have included devices such as keyboards, mice, displays, touchscreen, audio systems, and other interface devices. These accessories commonly connect via a USB connection. By way of established convention in the consumer electronics market, these accessories are typically low cost and limited in USB capability to act only as a USB Device. To connect them to a smart phone, the smart phone must be the USB Host. Therefore, leading mobile device manufacturers and system designers have begun designing their mobile device products (i.e. smart phones, tablets, etc.) to support both USB Host and USB Device roles. In other words, the phone may configure itself such that it can function as a USB Device when it needs to be, or as a USB Host when it needs to be. Recently, the system level design thinking has shifted towards viewing smart phones as the USB Host, and any device connecting thereto as the USB Device. Again, this is not surprising since this is exactly how

laptops and PCs work today. Extending this trend into the future, it can be predicted that the smart phone will act primarily as the USB Host, and will rarely or never act as a USB device. This presents some problems for automotive systems.

As explained previously, automotive systems have a USB Host and require USB Devices to connect to it. If a phone acts as a USB Host, then the system will not function since by USB convention, two USB Hosts cannot directly connect with each other. Automotive manufacturers desire compatibility with smart phones and are therefore motivated to adapt to this changing technology. A redesign of the USB architecture in the vehicle is thus necessary such that the vehicle can act either as the USB Host (when necessary to connect to USB Devices such as memory sticks, thumb drives, etc.) or USB Device (when necessary to connect to USB Hosts, such as a smart phone which demands to be USB Host rather than USB Device.

The USB organization has added a standard that addresses the need for devices to act as either USB Host or USB Device and as such can be considered a “dual role” USB controller. It is referred to in USB nomenclature as “On the Go” or “OTG” for short. Any device that meets the OTG standard can act as either USB Host or USB Device and can change roles dynamically. Therefore, one possible approach to modifying the vehicle USB architecture to support all use cases is to upgrade the vehicle’s USB Host to USB OTG. This solution addresses the issue but has some disadvantages. First, USB Hubs do not support OTG and can no longer be used in the system. Each consumer accessible USB port that supports OTG must have a dedicated wire link to a dedicated OTG controller in the Head Unit thus negating the wiring savings associated with use of USB Hubs. As a result several costly cables may need to be added to the vehicle’s electrical system. Second, there may not be enough OTG controllers available in the Head Unit to connect to each of the vehicle’s user accessible USB ports. This then forces the vehicle designer to choose a limited number of the many USB ports in the vehicle to support the OTG function and run dedicated USB cables to them. This can lead to user confusion and dissatisfaction since only certain consumer ports support the required functionality. Also, ports that support OTG may be co-located with other physically identical ports that do not. If the user chooses the wrong one, the applications they desire to run from the consumer device that requires USB Host mode won’t work.

Another possible solution is to implement custom USB hubs wherein the USB Hub is able to dynamically swap its upstream port with one it’s downstream ports when commanded to do so. System solutions built with this concept still require OTG controllers in the head unit but benefit from the fact that no additional wires need to be installed in the car. The existing USB cable between the USB OTG Host and the USB Hub can facilitate the necessary USB communications between the USB OTG controller in the Head Unit (HU) and a consumer device in USB Host (such as a smart phone). This solution also has some disadvantages however. For example, when the USB Hub is commanded to swap its upstream port with a downstream port, all other downstream ports of the USB Hubs lose their data connection with the Head Unit. While in this mode the Head Unit access to the other downstream ports of the hub cease. This may prevent use of certain vehicle system functions such as navigation or audio playback that may need consistent access to the other downstream ports of the hub to function. Furthermore, it

requires the HU to have an available USB OTG port and a signaling path to control the hub upstream/downstream port configuration.

SUMMARY

An object of an embodiment of the present invention is to provide a system which is configured to enable a vehicle’s embedded USB Host system to connect to mobile devices through a USB Hub, regardless of whether the mobile devices are configured to act as USB Hosts or USB Devices, without the need to provide OTG or dual role controllers in the head unit and without the need to provide additional cabling in the vehicle. Preferably, no hardware changes are required to be made to the USB Host circuits in the HU.

An embodiment of the present invention provides a system which can be employed between a vehicle’s embedded USB Host and at least one, but preferably multiple, consumer facing USB ports provided in the vehicle for connection to consumer devices. The system is configured to recognize and control whether the consumer device is required to be connected to each USB port as a USB Host or as a USB Device. Further, the system is able to dynamically switch the device connection between USB Device mode and USB Host mode when desired. In the case where the consumer device is acting as a USB Device, signals are routed normally through a USB Hub to the Head Unit. In the case where the consumer device is acting as a USB Host, signals between the consumer device and the vehicle’s embedded USB Host are routed and processed through a USB Host to Host Bridge which is connected to the USB Hub, thereby rendering the consumer device compatible with the vehicle’s embedded USB Host.

The present invention is capable of being implemented in several different embodiments. For example, an embodiment of the present invention comprises a USB Hub Module having a USB Hub, USB Bridge, and USB routing switches implemented as discrete devices. The USB Hub upstream port is configured to be connected to a vehicle’s embedded USB Host (such as a USB Host in a Head Unit). The USB Hub Module also includes a switching device (such as USB analog multiplexing switches for example) that is configured to route each consumer port to either the Bridge or the Hub. The USB Bridge is configured to effectively control the switching device. The USB Bridge is configured, based on signals from the Head Unit, whether the consumer device which is connected to the USB port is acting as USB Host or USB Device. In the case where the consumer device is acting as USB Host, the USB Bridge controls the switching device to route the USB port to the Bridge. The Bridge processes the signals from the consumer device and provides them to the USB Hub, thereby rendering the consumer device compatible with the vehicle’s embedded USB Host. In the case where the consumer device is acting as USB Device, the USB Bridge controls the switching device such that the switching device provides the signals to the USB Hub, effectively bypassing the Bridge.

Still another embodiment of the present invention provides that the USB routing logic, USB Bridge, and USB Hub are integrated in a single combination USB Hub/USB Bridge Integrated Circuit (IC).

Still other embodiments are entirely possible, some of which are described and illustrated herein. For example, the concept can be extended to include additional embedded USB Device functions such as USB HID and USB Audio. Further it is also envisioned that all consumer facing USB ports of the Hub Module can emulate or otherwise support

dual role USB capability provided that each downstream port has a Bridge to support USB Host mode for the connected device and a direct connection to the USB Hub to support USB Device mode. In all cases, compliance to USB protocols and architectures is preferably maintained.

BRIEF DESCRIPTION OF THE DRAWINGS

The organization and manner of the structure and operation of the invention, together with further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawings wherein like reference numerals identify like elements in which:

FIG. **1** illustrates a system wherein a multiple port self-powered USB Hub functions to connect a single USB Host to a plurality of USB ports;

FIG. **2** illustrates a system wherein a self-powered USB Hub provides not only a plurality of USB ports, but also a Secure Digital ("SD") card reader;

FIG. **3** illustrates a vehicle infotainment system structure wherein multiple USB Hubs are connected together or tiered, such that USB Hubs feed other USB Hubs;

FIG. **4** illustrates a system which is in accordance with an embodiment of the present invention, wherein a USB Hub, USB Bridge and a switching device are provided as discrete components;

FIG. **5** illustrates a system which is in accordance with an alternative embodiment of the present invention, wherein USB routing/switching logic and a USB Bridge are integrated with a USB Hub in a combination USB Hub/USB Bridge Integrated Circuit (IC);

FIG. **6** illustrates the different components of the combination USB Hub/Bridge IC shown in FIG. **5**;

FIG. **7** illustrates one possible endpoint configuration of the USB Bridge shown in FIGS. **5** and **6**; and

FIG. **8** illustrates an example implementation of a Head Unit Software Architecture.

DESCRIPTION OF ILLUSTRATED EMBODIMENTS

While this invention may be susceptible to embodiment in different forms, there are specific embodiments shown in the drawings and will be described herein in detail, with the understanding that the present disclosure is to be considered an exemplification of the principles of the invention, and is not intended to limit the invention to that as illustrated.

FIG. **4** illustrates a system which is in accordance with an embodiment of the present invention. The system is configured to effectively render a vehicle's embedded USB Host compatible with consumer devices which are configured to also act as USB Host or USB Device. The system is in the form of a self-powered USB Hub Module having a USB, a USB Bridge, and a switching device implemented as discrete devices. The USB Hub is preferably provided in the form of an integrated circuit (IC), and is configured (via an upstream USB port) connected to a vehicle's embedded USB Host (such as a USB Host in a Head Unit) via vehicle internal wiring, such as, in one embodiment, via a single USB data cable between the Head Unit and USB Hub. The USB Hub also includes a plurality of downstream USB ports, at least one of which is connected to a USB Bridge (which also is preferably provided in the form of an integrated circuit (IC)). At least one downstream USB port of the USB Hub is connected to a switching device (such as USB analog multiplexing switches, for example). The

switching device is configured to be connected to at least one USB port in the vehicle for connection to a consumer device. The USB Bridge is configured to effectively control the switching device although other control mechanisms are envisioned. The USB Hub Module is configured such that signals received from at least one USB port are received by the switching device, and the switching device routes the signals to the USB Bridge or the USB Hub. In the case where the consumer device is acting as USB Host, the USB Bridge processes the USB packets from the consumer port and provides them to the USB Hub, thereby rendering the consumer device compatible with the vehicle's embedded USB Host. In the case where the consumer device is acting as USB Device, the USB Bridge controls the switching device such that the switching device provides the USB signaling directly to the USB Hub, bypassing the Bridge.

As shown in FIG. **4**, the system also includes Power Management structure, as well as some other conventional structure not specifically shown in FIG. **4**, but which would be readily assumed to be present by one having ordinary skill in the art.

In use, the Head Unit controls the switching device via the USB Bridge hardware or any other convenient means of control. The HU software application may choose to enable, for example, a phone on any one of the consumer USB ports, by requesting, commanding or otherwise knowing the phone is required to be in USB Host mode and commanding the routing of the specific USB port the phone is attached to the USB Bridge. Once routed to the USB Bridge, the phone will detect a USB Device is connected and the phone will begin the standard USB enumeration sequence. The detection and enumeration processes are defined by USB standards and not explained here in detail. However, for purposes of describing the operation of the invention, a general understanding is provided herein. The enumeration process follows a strict sequence of USB descriptor requests from the USB Host and USB descriptor responses from the USB Device that allow the Host to determine the capabilities and functions of the Device and configure the USB Device for operation. Once the complete set of device descriptors are known the USB Host will then load the appropriate USB driver(s) and applications to support in the functionality that the USB Device provides. In the scope of this invention it is envisioned that the responses to the descriptor requests made by the phone (USB Host) are either answered locally by the Bridge or preferably, the requests are forwarded through the Bridge to the Head Unit where its device drivers process the request and return the response. The descriptor responses from the device driver are conveyed to the USB Bridge, which then, in turn, passes them to the phone. By passing descriptor request to the Head Unit drivers and returning the responses from the Head Unit drivers back to the consumer device, the Bridge appears as a transparent component in the USB system architecture. The system capabilities are controlled by the Head Unit and the system remains flexible without need for changes to the Bridge firmware or hardware when the system designer requires changes to the descriptor responses. Once the consumer device completes the enumeration process, the Head Unit's USB functional capabilities are known to the consumer device and the consumer device may enable use of those functions over USB communication. At this point, the consumer device or the Head Unit may begin activating any number of supported services such as data connections, streaming audio and streaming video to and from the vehicle via the USB Bridge.

Another embodiment of the present invention can be provided, wherein the bridge is configured to act as an OTG port thus negating the need for switches and/or routing logic. In this case there would exist one Bridge functional block for each downstream port. This embodiment would effectively be a more generalized case of the example illustrated in FIG. **4**. FIG. **4** shows just one Bridge that any one of the consumer USB ports can be routed to. With just one bridge, only one consumer USB port can be connected to a USB host at a time. However, if each downstream port of the Hub has a dedicated Bridge, then multiple consumer ports can support connection to USB Host devices at the same time. Thus, any consumer port can be in either USB Host or USB Device mode at any time independently of the others.

FIG. **5** illustrates an alternative embodiment wherein the switching device comprises USB routing logic, and both the USB routing logic and the USB Bridge are integrated with the USB Hub in a combination USB Hub/USB Bridge Integrated Circuit (IC). This configuration has cost and size advantages over building it with discrete components connected together on a printed circuit board.

FIG. **6** illustrates the internal components of the USB Hub/USB Bridge Integrated Circuit (IC) shown in FIG. **5**. As shown, preferably the components of the USB Bridge include a bridge controller as well as endpoint buffers. While the exact configuration of endpoints is effectively up to the system designer to choose for a particular need, a specific example of one possible endpoint configuration is shown in FIG. **7**; however, many others are possible.

As shown in FIG. **7**, the endpoints of the Bridge may be designed to support multiple pipes of Bulk USB data connections between the Host A (Head Unit) and Host B (consumer device). In the Bridge, the IN endpoints of Device A are connected to the OUT endpoints of Device B and the OUT endpoints of Device A are connected to the IN endpoints of Device B. The design of the Bridge may be such that the data flow between the endpoints may be direct or buffered. For example, in the case of direct connection, once a USB packet is received from Host A on a Device A OUT endpoint, the internal logic of the Bridge moves to packet to the Device B IN endpoint if it is available. If Device B IN endpoint is full or otherwise not available then subsequent attempts of Host A to send more packets to Device A in the Bridge will be rejected until such time that the Device B IN endpoint is clear and the contents of the Device A OUT buffer is moved to it. Alternatively, there may exist a local buffer in the Bridge between the endpoints of Device A and B. For example, packets received on an OUT endpoint of Device A are placed in a local memory device for temporary storage until Device B IN endpoint is ready for them. The OUT endpoints are thus capable of receiving multiple packets from the Host until the buffer is full. Likewise the IN endpoints may, at times, transmit multiple packets until the buffer is empty. Such buffers are not required, but are envisioned, to improve system throughput performance in certain circumstances where one of the USB Hosts is occasionally busy and not keeping up with USB transactions at the same rate as the other USB Host. Regardless of the buffer configuration, the Bridge hardware has IN and OUT endpoints on Device A mapped to OUT and IN endpoints respectively on Device B, thus forming a bidirectional bridge that passes USB traffic between two USB Hosts with bandwidth sufficient to support the application requirements of the system.

Also shown in FIG. **7**, Device A and Device B provide a bidirectional Control endpoint connected to their respective USB Hosts. Control endpoints are required per USB standard to support USB defined control messages between the Host and Device both during and after the enumeration sequence. Optionally, USB endpoints may also be utilized per USB standard to employ messages intended to control user defined custom device specific behavior, referred to as Vendor Specific messages. As can be seen in FIG. **7**, the Control endpoints are mapped to the Bridge Controller (BC). The BC logic may be implemented in hardware or preferably software. The BC provides the capability to send, receive and process USB standard Control endpoint messages as well as vendor specific messages essential to the control and operation of the Bridge. At system startup, the A Host requests and receives descriptors from the BC via the Control endpoint. Once complete, Host A then loads the Bridge Driver in its software stack and configures the custom Bridge hardware for operation. Host A can then control the functions of the Bridge, such as USB switch routing control. The system is now ready to accept connection with USB Host mode consumer devices on the B Device of the Bridge. When such a connection is made, the BC will notify the Bridge Driver in Host A by sending a message on the control endpoint to Host A. Further, Host B will begin sending descriptor requests on the control endpoint to Device B in Bridge. The BC receives theses requests, encapsulates them with information that identifies them as descriptor requests from Host B and passes them to the Bridge Driver on Host using the control endpoint. Host A Bridge Driver receives these requests, identifies them as descriptor requests and passes the requests on to other software components in Host A system and waits for the descriptor responses. The descriptor responses are encapsulated by the Bridge driver to indicate they are descriptor responses that are to be forwarded to Host B. The response is then sent to the BC via the control endpoint. The BC receives them, identifies them as descriptor responses that should be forwarded to Device B and places them on the control endpoint for Device B. This process of receiving and forwarding messages back and forth between the two hosts continues until the enumeration process is complete with Host B. From that point on the two hosts may begin to use the IN and OUT endpoints to transfer application data and services over the bulk endpoints.

FIG. **8** illustrates one possible configuration of the system architecture including software components in the Head Unit interfacing with the Bridge/Hub. There are multiple ways that the operating system and software architecture can be constructed to support the functions of the USB Bridge/Hub. In FIG. **8**, a typical Linux implementation is shown including the Bridge/Hub Module and the Head Unit. The system design utilizes standard Linux Kernel components and configurations and should be familiar to those skilled in the art. The Head Unit USB Host Controller hardware is driven by the Host Controller Driver. The Host Controller Driver is connected to the USB Core. The USB Core connects the HCD with the standard USB Linux Device Drivers and the custom Bridge Driver. The Bridge Driver is configured to optionally connect directly to the User Space Application software or to the USB Gadget Driver depending on system architecture. The custom Bridge Driver plays a dual role of both controlling the functions of the Bridge hardware as well as providing a data path between the gadget device drivers and applications running on the Head Unit. The architecture illustrated is capable of handling both the operation and data paths associated with the Bridge and the Hub at the same time, thus allowing concurrent operation of consumer devices operating in USB Device mode with consumer devices operating in USB Host mode. In one

embodiment, the Hub/Bridge supports simultaneous active USB data connections between the Head Unit and multiple consumer devices, at least one of which being in host mode while the others are in device mode. In another embodiment, the Hub/Bridge supports simultaneous active USB data connections between the Head Unit and some combination of embedded and consumer USB devices along with at least one device being in host mode. While it is understood that the software functions of the head unit are essential to building a complete system, the designs of which can vary significantly and this example is provided only as a means of demonstrating one way to utilize the functionality of the present invention.

What is claimed is:

1. A method of supporting data communication between a USB host and a USB enabled consumer device capable of operating in either a USB host mode or in a USB device mode, said method comprising the steps of:

providing a USB hub having a plurality of USB ports interconnected to the USB host, said USB hub configured to simultaneously broadcast data from the USB host to each USB port in the plurality of USB ports and to transmit data from each USB port to the USB Host;

providing a USB bridge interconnected to the USB hub and configured to connect the USB host to a second USB host;

providing a USB routing switch interconnected to the USB bridge, the USB hub, and the plurality of USB ports;

automatically configuring the USB routing switch to connect a first USB Port of the plurality of USB ports to the USB hub through the USB bridge when a consumer device connected to the USB host mode port is the second USB host; and

automatically configuring the USB routing switch to initiate bidirectional communication with the USB host, wherein the USB routing switch is configured to connect the first USB port directly to the USB hub when the consumer device connected to the first USB port is configured to only respond to communication from the USB host, thereby rendering the consumer device compatible with the USB host.

2. The method according to claim **1**, further comprising the steps of:

determining, via the USB routing switch, if the consumer device is operating in a USB host mode or in a USB device mode;

connecting the consumer device to the USB hub through the USB routing switch and the USB bridge when the USB routing switch determines the consumer device is in the USB host mode; and

connecting the consumer device to the USB hub through the USB routing switch and the USB hub thereby bypassing the USB bridge when the USB routing switch determines the consumer device is the USB device mode.

3. The method according to claim **1**, further comprising the step of:

automatically recognizing whether the consumer device connected to the USB Port is the second USB Host or the USB Device and control the USB routing switch accordingly.

4. The method according to claim **2**, further comprising the step of:

dynamically switching operation of USB Ports connected to the USB Hub Module between USB Device mode and USB Host mode.

5. The method according to claim **1**, further comprising the step of:

connecting each consumer device of the plurality of consumer devices, via the USB routing switch, to either the USB Bridge or the USB Hub based on whether each consumer device attached to each USB Port in the plurality of USB Ports is the USB Host or the USB Device.

6. The method according to claim **1**, further comprising the step of:

controlling the USB routing switch via the USB bridge.

* * * * *

EXHIBIT E

US011176072B2

(12) **United States Patent**
Voto et al.

(10) **Patent No.: US 11,176,072 B2**
(45) **Date of Patent: *Nov. 16, 2021**

(54) **FLEXIBLE MOBILE DEVICE CONNECTIVITY TO AUTOMOTIVE SYSTEMS WITH USB HUBS**

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(73) Assignee: **APTIV TECHNOLOGIES LIMITED**

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 50 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **16/660,083**

(22) Filed: **Oct. 22, 2019**

(65) **Prior Publication Data**

US 2020/0057739 A1 Feb. 20, 2020

Related U.S. Application Data

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(51) **Int. Cl.**
G06F 13/38 (2006.01)
G06F 13/40 (2006.01)
G06F 13/42 (2006.01)

(52) **U.S. Cl.**
CPC .... ***G06F 13/385*** (2013.01); ***G06F 13/4022*** (2013.01); ***G06F 13/4045*** (2013.01); (Continued)

(58) **Field of Classification Search**
CPC G06F 13/4022; G06F 13/385; G06F 13/4045; G06F 13/4282; G06F 2213/4004; G06F 2213/3812; G06F 11/3051
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,073,188	A	6/2000	Fleming
6,732,219	B1	5/2004	Broyles

(Continued)

FOREIGN PATENT DOCUMENTS

GB	2473123	A	3/2011
JP	2003256351	A	9/2003

(Continued)

OTHER PUBLICATIONS

"FFI Rapport—A Study of Computer Interfaces for Soldier Systems", Lars Erik Olsen & Joakin Flathagen, Norwegian Defence Research Establishment, Oct. 10, 2005.

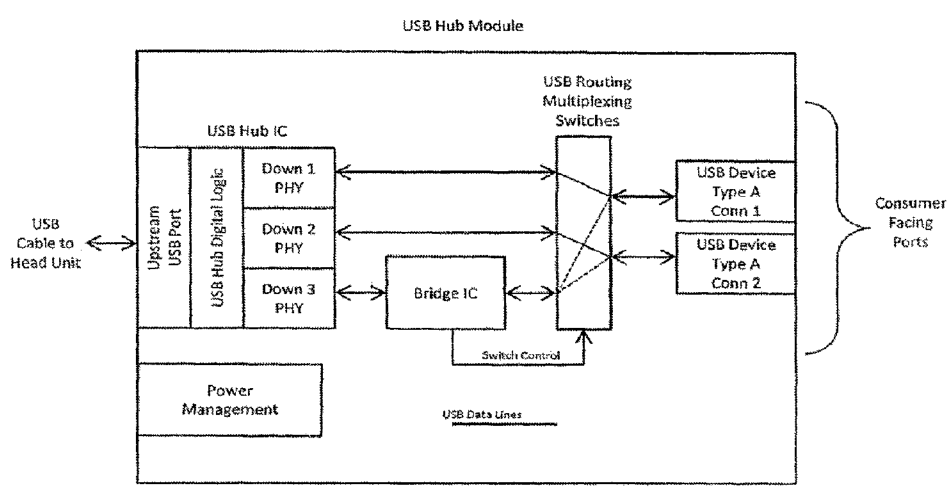
(Continued)

Primary Examiner — Ernest Unelus
(74) *Attorney, Agent, or Firm* — Billion & Armitage

(57) **ABSTRACT**

A method to enable a vehicle's embedded USB Host system to connect to multiple mobile devices through a USB Hub, regardless of whether the mobile devices are configured to act as USB Hosts or USB Devices, without USB On the Go (OTG) controllers or additional vehicle wiring, or inhibiting the functionality of any consumer devices connected to the same USB Hub. Preferably, the method is configured to provide that no additional cabling is required, and no hardware changes are required to be made to the HU. The method can be employed between a vehicle's embedded USB Host, USB Hub and at least one consumer accessible USB port. When the consumer device is acting as a USB Host, signals between the consumer device and the vehicle's embedded USB Host are processed through a USB bridge, thereby rendering the consumer device compatible with the vehicle's embedded USB Host.

1 Claim, 8 Drawing Sheets



Related U.S. Application Data

continuation of application No. 15/268,728, filed on Sep. 19, 2016, now Pat. No. 9,619,420, which is a continuation of application No. 14/487,947, filed on Sep. 16, 2014, now Pat. No. 9,460,037.

(60) Provisional application No. 61/882,915, filed on Sep. 26, 2013.

(52) **U.S. Cl.**
CPC .. ***G06F 13/4282*** (2013.01); *G06F 2213/0042* (2013.01); *G06F 2213/3812* (2013.01); *G06F 2213/4004* (2013.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,934,793	B2	8/2005	Ying et al.	
6,957,287	B2	10/2005	Lou et al.	
7,130,656	B2	10/2006	Okagaki et al.	
7,280,802	B2	7/2007	Grady	
7,478,191	B2	1/2009	Wurzburg et al.	
7,502,878	B1 *	3/2009	Wright	G06F 13/4022 710/37
7,523,243	B2	4/2009	Bohm et al.	
7,627,708	B2	12/2009	Bohm et al.	
8,447,598	B2	5/2013	Chutorash et al.	
8,447,890	B1	5/2013	LeTourneur et al.	
2003/0167345	A1	9/2003	Knight et al.	
2004/0019732	A1	1/2004	Overtoom et al.	
2004/0088449	A1	5/2004	Sakaki	
2004/0243755	A1	12/2004	Lee et al.	
2006/0056401	A1	3/2006	Bohm et al.	
2006/0206650	A1	9/2006	Chang	
2007/0067553	A1	3/2007	Chang	
2007/0086724	A1	4/2007	Grady et al.	
2007/0156293	A1	7/2007	Kellzi et al.	
2007/0255885	A1 *	11/2007	Bohm	G06F 13/4022 710/316
2008/0005262	A1	1/2008	Wurzburg et al.	
2009/0117890	A1	5/2009	Jacobsen et al.	
2011/0054721	A1	3/2011	Goodrich et al.	
2011/0124300	A1	5/2011	Sinai	
2012/0134506	A1	5/2012	DeBiasio et al.	
2012/0191811	A1	7/2012	Ng et al.	
2012/0290859	A1	11/2012	Saladin et al.	
2013/0053003	A1	2/2013	King, II	
2013/0106750	A1	5/2013	Kurosawa	
2015/0089092	A1	3/2015	Voto et al.	

FOREIGN PATENT DOCUMENTS

TW	470887	B	1/2002
WO	2007147114	A2	12/2007
WO	2015081448	A1	6/2015

OTHER PUBLICATIONS

"USB 2.0 Autoswitch User's Manual", Lindy Electronics Limited & Lindy-Elektronic GMBH, Sep. 2002.
"APC USB 2.0 Host Controller—Device Driver Download", http://www.liutilities.com/devicedriver/apcusb20hostcontroller/, Jul. 2002.
"Peripheral-Sharing Hardware Suits Education's Needs to a 'T'", Terian Tyre, T H E Journal (Technological Horizons In Education), Oct. 1988.
"Universal Serial Bus Specification Revision 2.0", Universal Serial Bus Specification No. REV. 2.0, Apr. 27, 2000.
Examination Report for IN Application No. 201647014322, dated Dec. 17, 2020, 5 pages.

* cited by examiner

Figure 1

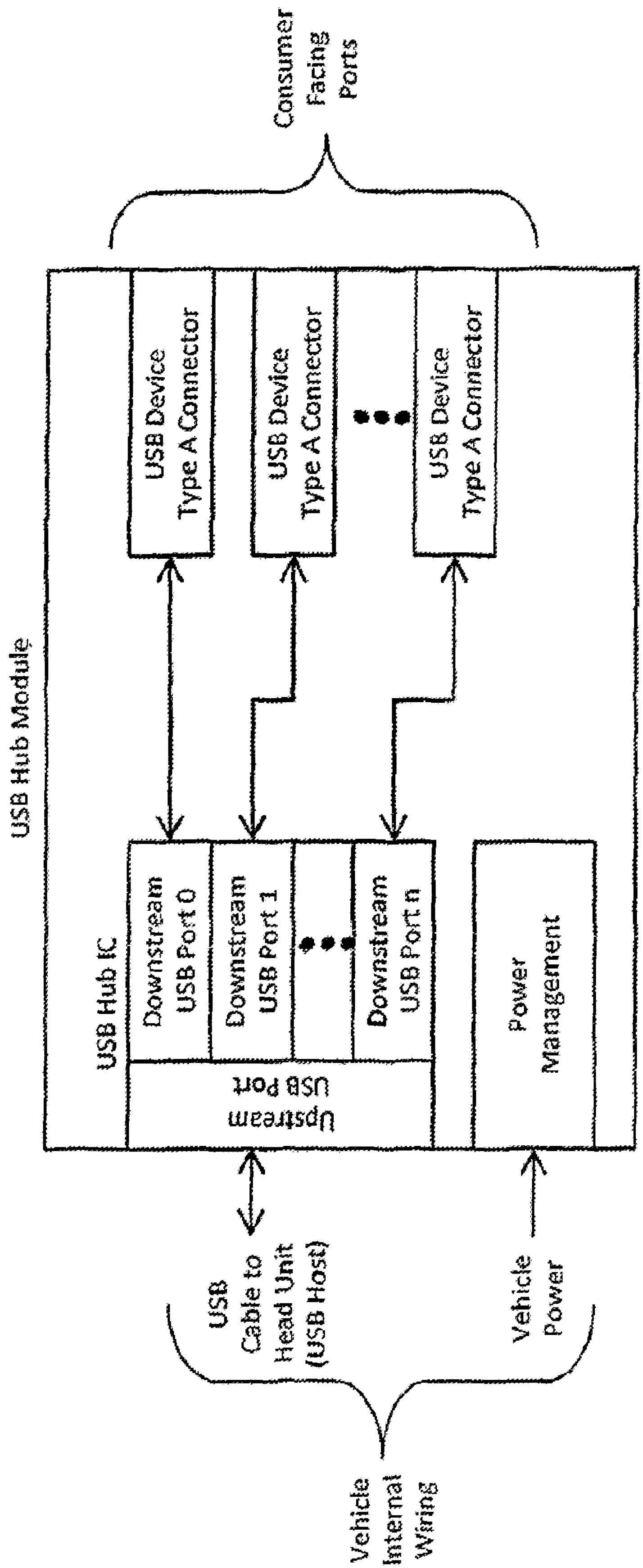

Consumer Facing Ports
USB Hub Module
USB Device Type A Connector
USB Device Type A Connector
USB Device Type A Connector
USB Hub IC
Downstream USB Port 0
Downstream USB Port 1
Downstream USB Port n
Upstream USB Port
Power Management
USB Cable to Head Unit (USB Host)
Vehicle Power
Vehicle Internal Wiring

Figure 2

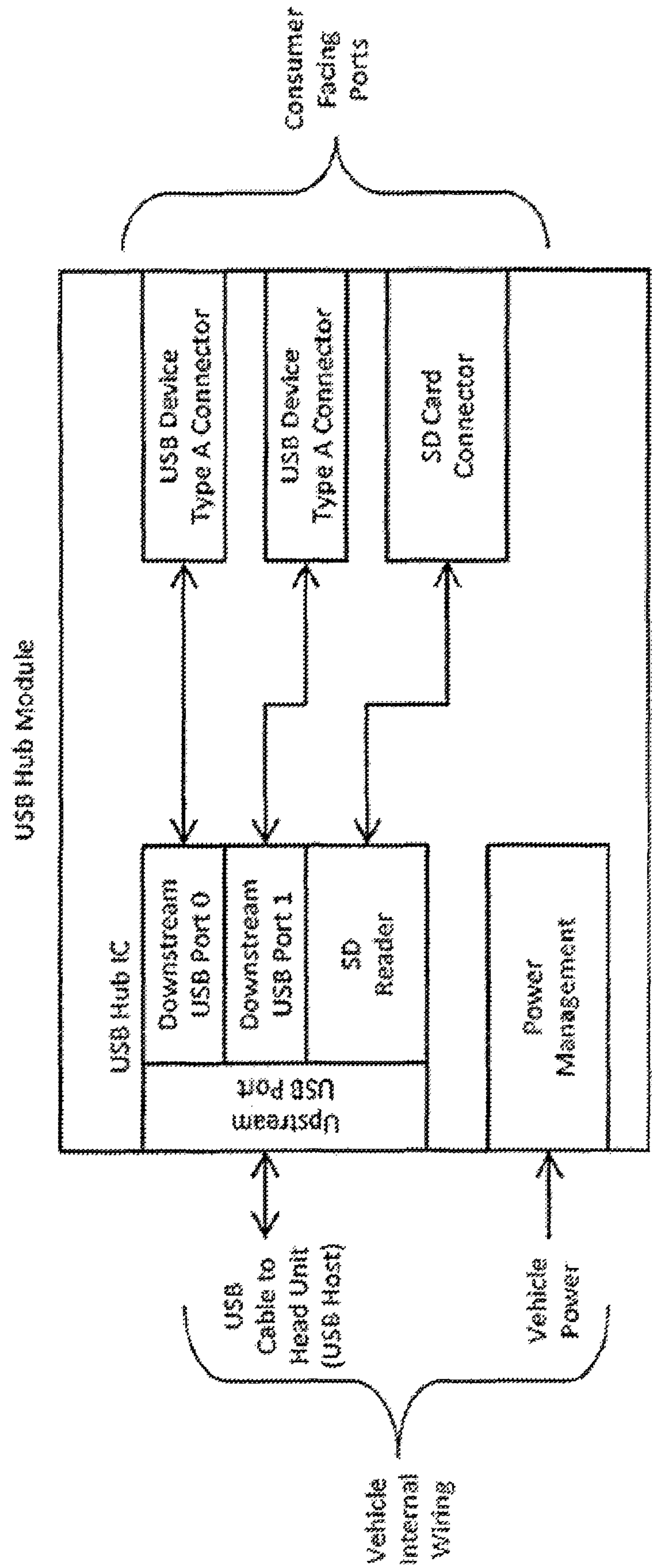
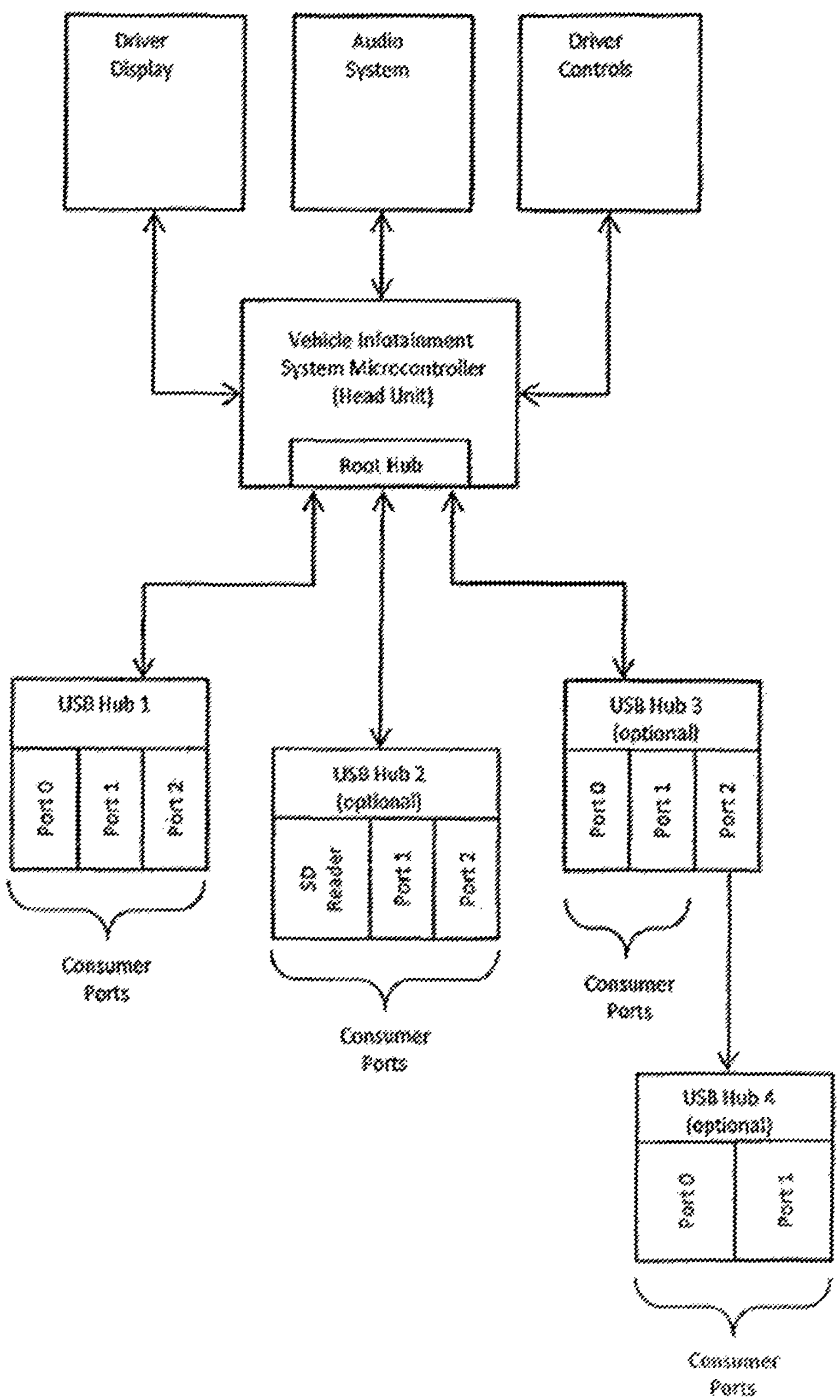

Consumer Facing Ports
USB Hub Module
USB Device Type A Connector
USB Device Type A Connector
SD Card Connector
USB Hub IC
Downstream USB Port 0
Downstream USB Port 1
SD Reader
Upstream USB Port
Power Management
USB Cable to Head Unit (USB Host)
Vehicle Power
Vehicle Internal Wiring

Figure 3


Driver Display
Audio System
Driver Controls
Vehicle Infotainment System Microcontroller (Head Unit)
Root Hub
USB Hub 1
Port 0
Port 1
Port 2
Consumer Ports
USB Hub 2 (optional)
SD Reader
Port 1
Port 2
Consumer Ports
USB Hub 3 (optional)
Port 0
Port 1
Port 2
Consumer Ports
USB Hub 4 (optional)
Port 0
Port 1
Consumer Ports

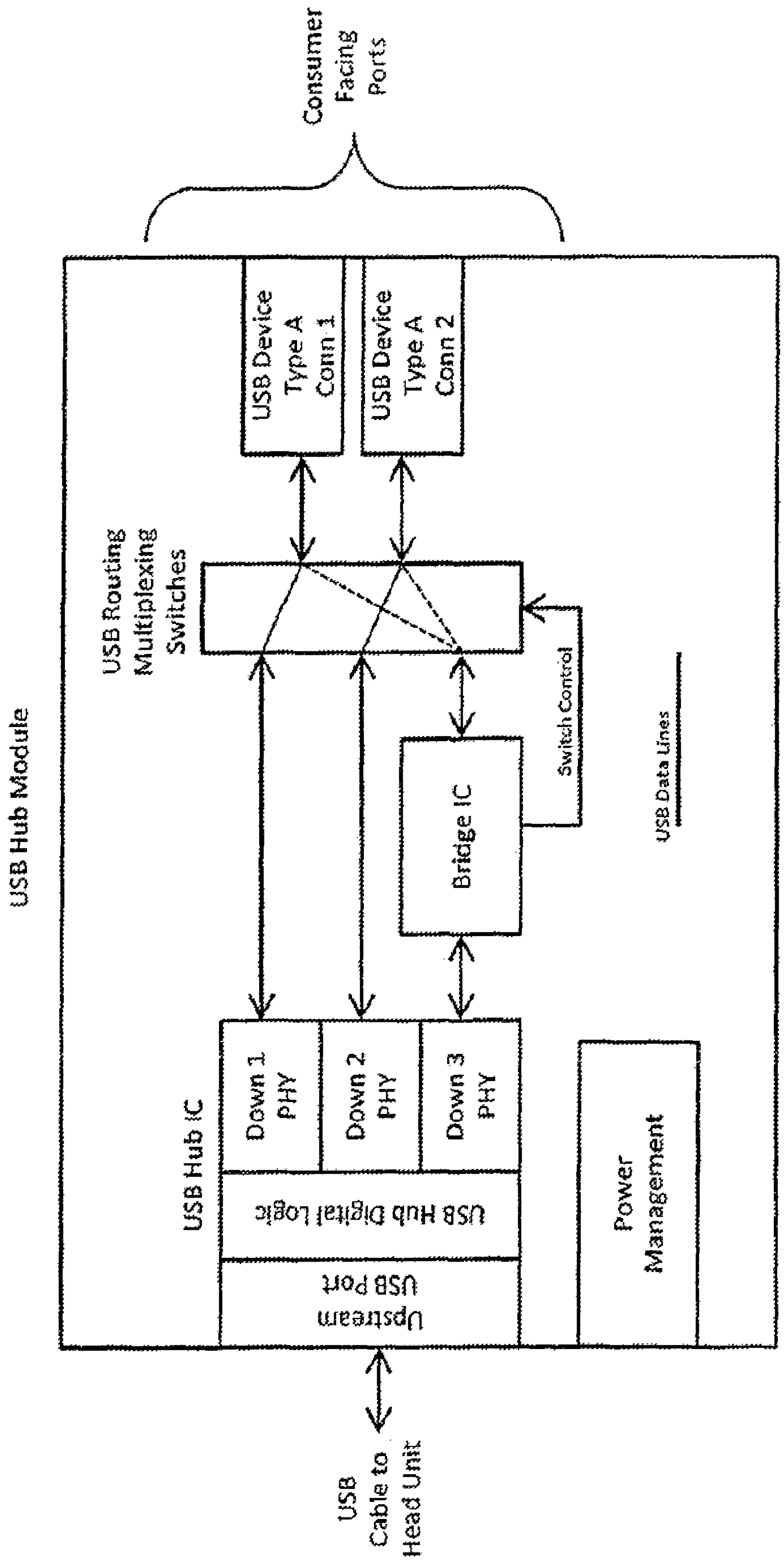
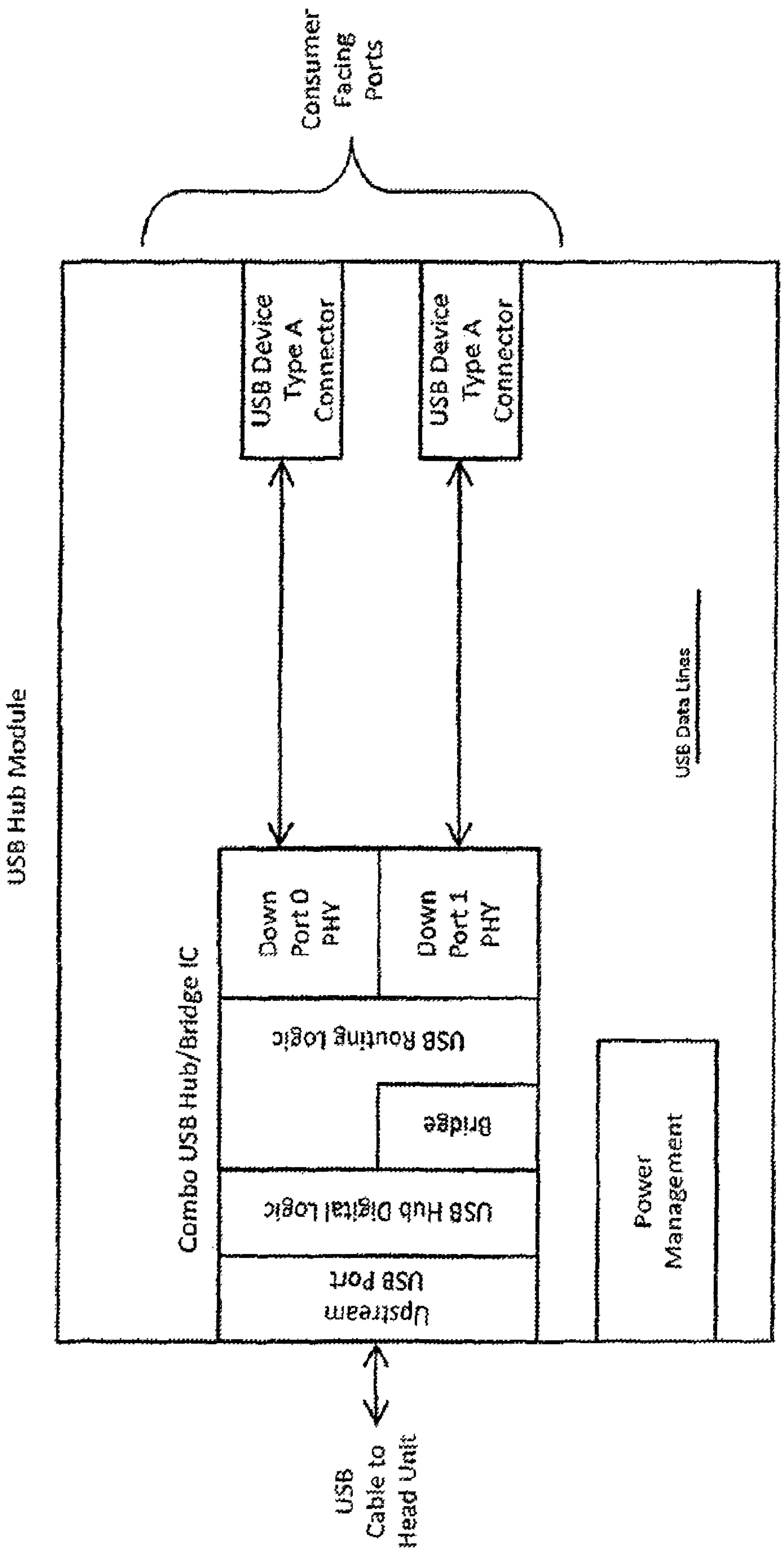

Consumer Facing Ports
USB Hub Module
USB Device Type A Conn 1
USB Device Type A Conn 2
USB Routing Multiplexing Switches
Switch Control
Bridge IC
USB Data Lines
USB Hub IC
Down 1 PHY
Down 2 PHY
Down 3 PHY
USB Hub Digital Logic
Upstream USB Port
Power Management
USB Cable to Head Unit

Figure 4

Figure 5


Consumer Facing Ports
USB Device Type A Connector
USB Device Type A Connector
USB Hub Module
USB Data Lines
Combo USB Hub/Bridge IC
Down Port 0 PHY
Down Port 1 PHY
USB Routing Logic
Bridge
USB Hub Digital Logic
Upstream USB Port
Power Management
USB Cable to Head Unit

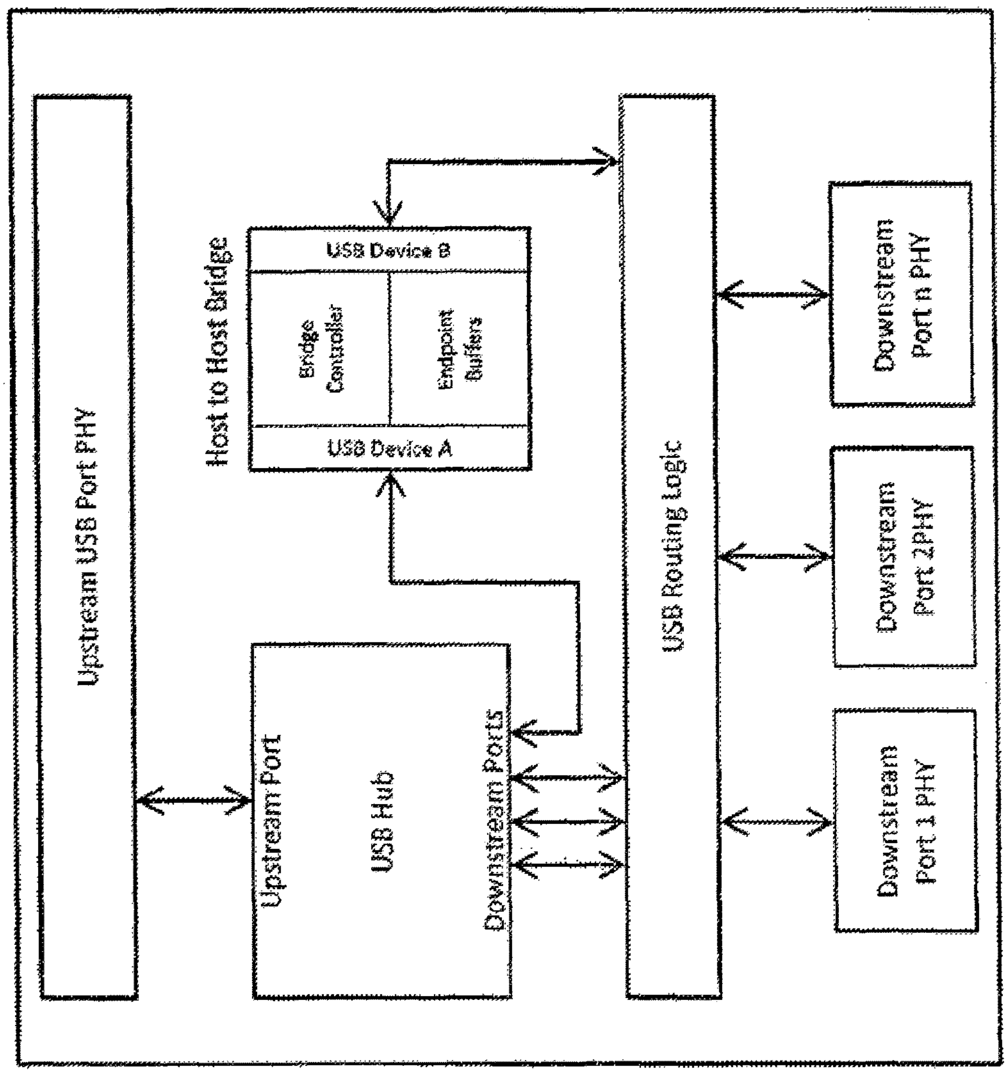

Upstream USB Port PHY
Host to Host Bridge
USB Device B
Bridge Controller
Endpoint Buffers
USB Device A
Upstream Port
USB Hub
Downstream Ports
USB Routing Logic
Downstream Port n PHY
Downstream Port 2PHY
Downstream Port 1 PHY

Figure 6

Figure 7

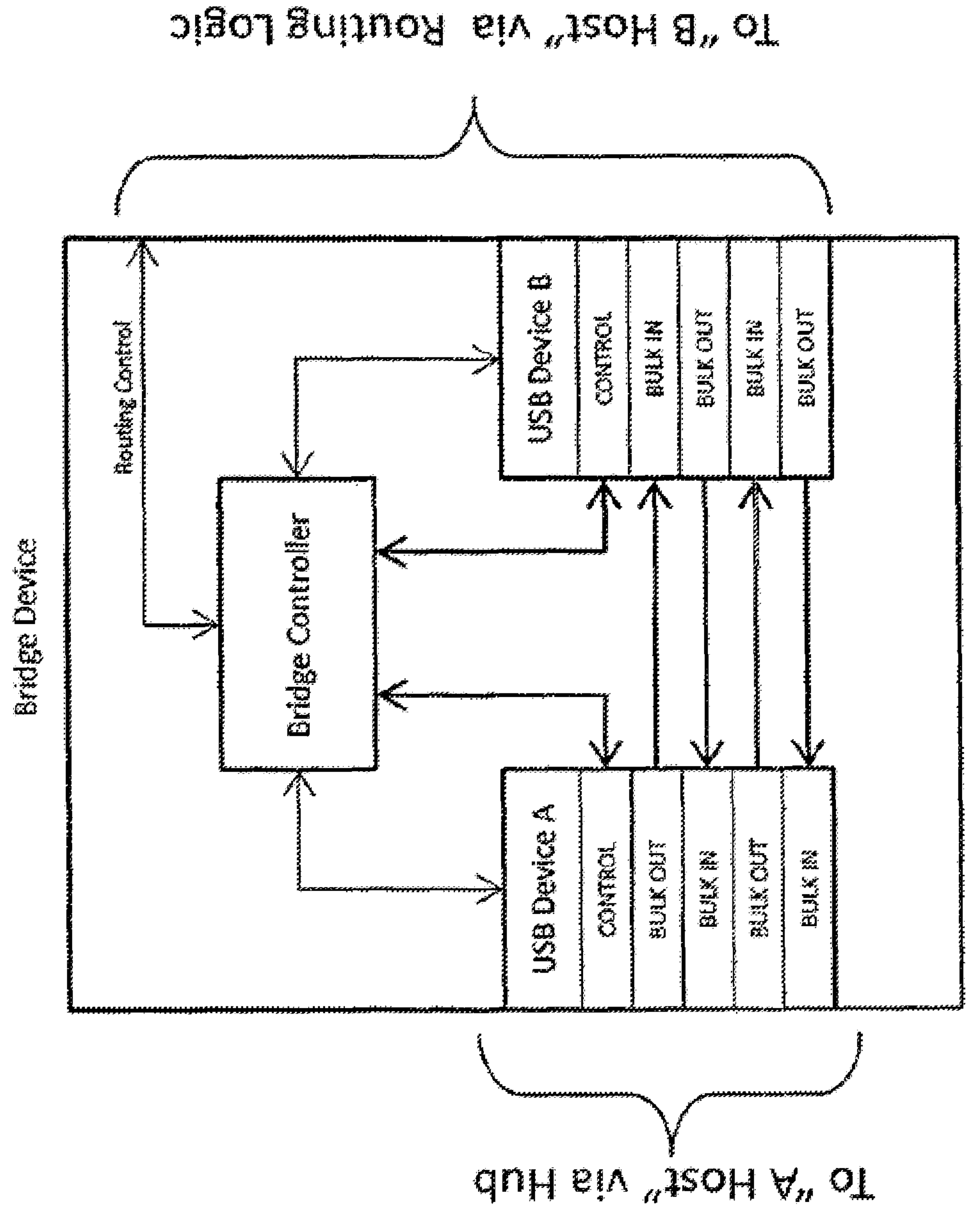
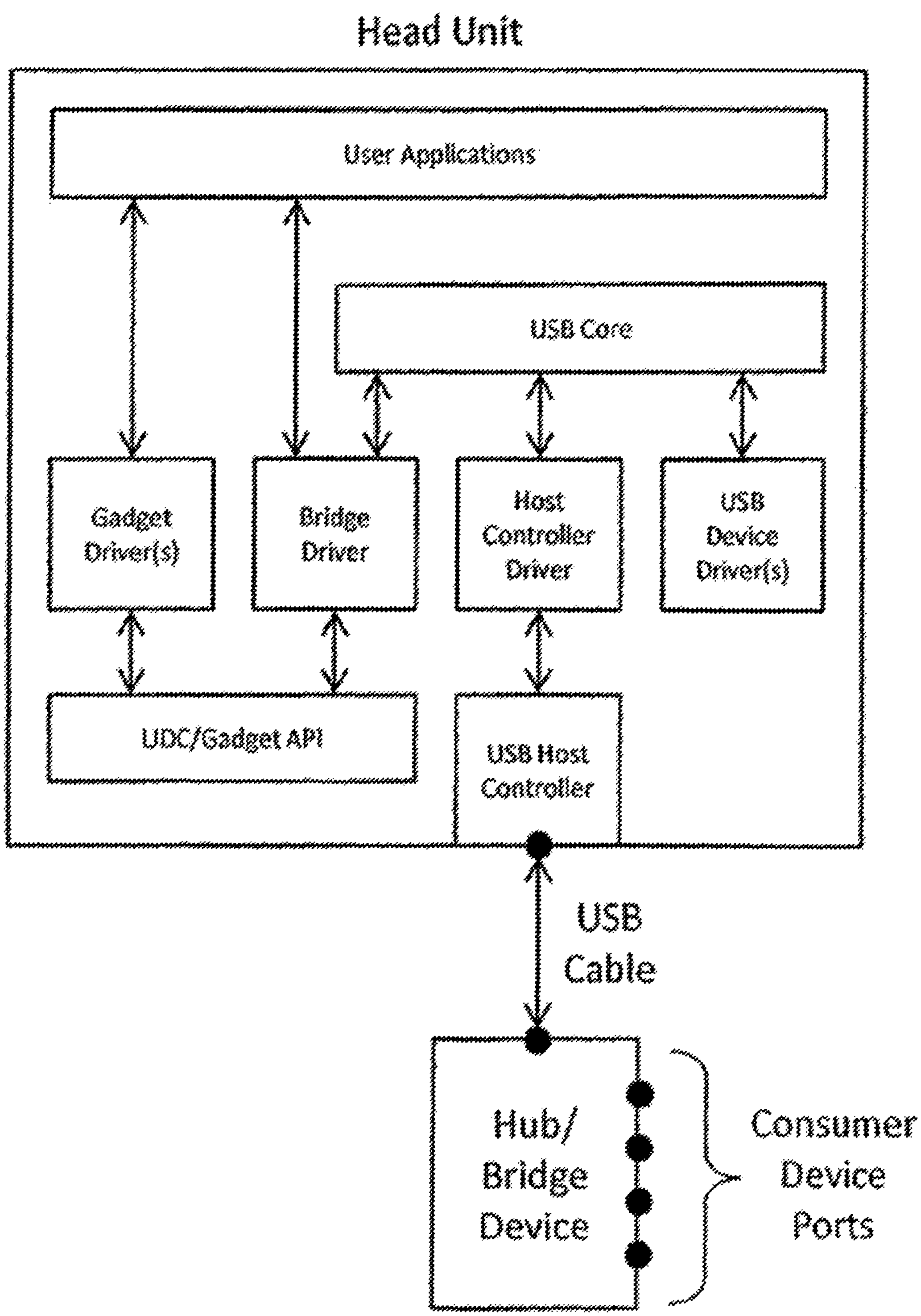

To "B Host" via Routing Logic
Bridge Device
Routing Control
Bridge Controller
USB Device B
CONTROL
BULK IN
BULK OUT
BULK IN
BULK OUT
USB Device A
CONTROL
BULK OUT
BULK IN
BULK OUT
BULK IN
To "A Host" via Hub

Figure 8


Head Unit
User Applications
USB Core
Gadget Driver(s)
Bridge Driver
Host Controller Driver
USB Device Driver(s)
UDC/Gadget API
USB Host Controller
USB Cable
Hub/ Bridge Device
Consumer Device Ports

FLEXIBLE MOBILE DEVICE CONNECTIVITY TO AUTOMOTIVE SYSTEMS WITH USB HUBS

RELATED APPLICATIONS

This application is a continuation application and claims benefit under 35 U.S.C. § 120 of U.S. patent application Ser. No. 15/441,775, filed Feb. 24, 2017, which claimed benefit of U.S. patent application Ser. No. 15/268,728, now U.S. Pat. No. 9,619,420, filed Sep. 19, 2016, which claimed benefit under 35 U.S.C. § 120 of U.S. patent application Ser. No. 14/487,947, now U.S. Pat. No. 9,460,037, filed on Sep. 16, 2014, which claimed benefit under 35 U.S.C. § 119(e) of U.S. Provisional Patent Application No. 61/882,915, filed on Sep. 26, 2013, the entire disclosure of each of which are hereby incorporated herein by reference.

BACKGROUND

The present invention generally relates to Universal Serial Bus ("USB") connectivity between, for example, mobile consumer devices and vehicle electronic systems. More specifically, the present invention relates to a system which is configured to provide that consumer devices that act as either USB host or USB device can connect to a vehicle's embedded USB host that does not have On the Go ("OTG") capability through an embedded USB hub in the vehicle.

Historically, mobile consumer devices such as media players, smart phones, tablets and the like have relied on connections to other devices, such as laptop or desktop personal computers ("PC's") to acquire content, exchange data, and charge the device's internal battery. For many years now, that has been accomplished through USB ports on each device. The use of USB technology is suitable for such needs since it is commonly available, familiar to the end user, cost effective and ubiquitous. USB protocols require a point-to-point connection in which one end is the USB Host or master, and the other end is a USB Device or slave. In this way, the flow of messages between the two devices is managed and controlled, whereby the USB Device responds to messages initiated by the USB Host. Historically, PC's have provided USB Host ports for connection to simpler USB Devices such as printers, memory sticks, mobile phones, etc. The USB Host has a greater burden of software and hardware requirements than a USB Device, so it has made sense to designate the PC as the USB Host in such systems.

In vehicle systems that employ USB connections, the same concepts apply. In such systems, the vehicle is typically the USB Host. The USB Host function is often embedded into a component of the vehicle infotainment system, such as into the radio or other control module. Typically, multiple USB ports are strategically designed into the vehicle in locations convenient for the driver and passengers to connect their consumer devices. Once a consumer device is connected to one of the ports, the device begins charging and the vehicle infotainment system can access content on the consumer device. This is useful to enable features such as streaming music, video and other services the device may provide.

Such a system requires that each of the USB ports be physically connected to the vehicle's USB Host in a manner suitable for USB data flow. This is accomplished through electrical cabling which is embedded in the vehicle, and which connects each of the ports to the USB Host. Since there can be many USB ports in a vehicle, and each port

requires a cable to connect the port to the USB Host, it is desirable to share cabling when possible to minimize cost and mass of the vehicle. This is accomplished through the use of USB Hubs. USB Hubs allow a single USB Host to connect to multiple USB Devices over a single cable between the USB Host and the USB Hub. As shown in FIGS. **1** and **2**, a single USB Hub can connect one USB Host to several USB Devices. Specifically, FIG. **1** illustrates a system wherein a self-powered USB Hub having a plurality of USB ports connects to a plurality of USB Devices (via a plurality of consumer-facing USB ports), while FIG. **2** illustrates a system wherein a self-powered USB Hub provides not only a plurality of USB ports which are in communication with a plurality of consumer-facing USB ports, but also a Secure Digital ("SD") card reader which is connected to a consumer-facing SD card connector. Other portions of FIGS. **1** and **2**, such as Power Management, are standard in the industry and self-explanatory upon viewing FIGS. **1** and **2**.

Furthermore, as shown in FIG. **3**, multiple USB Hubs can be tiered, such that USB Hubs connect to other USB Hubs. Specifically, FIG. **3** illustrates a vehicle system architecture that includes a central vehicle microcontroller (also referred to as the Head Unit or "HU"). Connected to the Head Unit are components or systems such as displays, the audio system, entertainment system and the driver controls. The Head Unit may be architected as a single module encompassing all functions or distributed such that various functions are managed by individual modules. The Head Unit includes a Root USB Hub which is typically connected to one or more downstream USB Hubs distributed throughout the vehicle. Each USB Hub has a plurality of downstream ports (at least one of which may be an SD reader or USB audio device), thereby effectively providing that each USB port in the vehicle has a connection to the USB Host or Head Unit. In FIG. **3**, for example, the Root Hub is embedded in the radio, and is connected to four (4) self-powered USB Hubs, wherein one is in the vehicle's center console, one is in the vehicle's center stack, and two are in the vehicle's rear seats.

Recently, mobile devices such as smart phones have gained in popularity. This is, in part, due to their usefulness as standalone computing devices. With advances in consumer electronic technology and increases in the speed of mobile networks, these devices are no longer reliant on being connected to PCs to access content. These smart mobile devices now have many of the same hardware resources, connectivity and software operating systems that only PCs had in past years. As has been the case with desktop PCs, accessories for these mobile devices have become available to aid in their ease of use. These accessories have included devices such as keyboards, mice, displays, touchscreen, audio systems, and other interface devices. These accessories commonly connect via a USB connection. By way of established convention in the consumer electronics market, these accessories are typically low cost and limited in USB capability to act only as a USB Device. To connect them to a smart phone, the smart phone must be the USB Host. Therefore, leading mobile device manufacturers and system designers have begun designing their mobile device products (i.e. smart phones, tablets, etc.) to support both USB Host and USB Device roles. In other words, the phone may configure itself such that it can function as a USB Device when it needs to be, or as a USB Host when it needs to be. Recently, the system level design thinking has shifted towards viewing smart phones as the USB Host, and any device connecting thereto as the USB

Device. Again, this is not surprising since this is exactly how laptops and PCs work today. Extending this trend into the future, it can be predicted that the smart phone will act primarily as the USB Host, and will rarely or never act as a USB device. This presents some problems for automotive systems.

As explained previously, automotive systems have a USB Host and require USB Devices to connect to it. If a phone acts as a USB Host, then the system will not function since by USB convention, two USB Hosts cannot directly connect with each other. Automotive manufacturers desire compatibility with smart phones and are therefore motivated to adapt to this changing technology. A redesign of the USB architecture in the vehicle is thus necessary such that the vehicle can act either as the USB Host (when necessary to connect to USB Devices such as memory sticks, thumb drives, etc.) or USB Device (when necessary to connect to USB Hosts, such as a smart phone which demands to be USB Host rather than USB Device.

The USB organization has added a standard that addresses the need for devices to act as either USB Host or USB Device and as such can be considered a "dual role" USB controller. It is referred to in USB nomenclature as "On the Go" or "OTG" for short. Any device that meets the OTG standard can act as either USB Host or USB Device and can change roles dynamically. Therefore, one possible approach to modifying the vehicle USB architecture to support all use cases is to upgrade the vehicle's USB Host to USB OTG. This solution addresses the issue but has some disadvantages. First, USB Hubs do not support OTG and can no longer be used in the system. Each consumer accessible USB port that supports OTG must have a dedicated wire link to a dedicated OTG controller in the Head Unit thus negating the wiring savings associated with use of USB Hubs. As a result several costly cables may need to be added to the vehicle's electrical system. Second, there may not be enough OTG controllers available in the Head Unit to connect to each of the vehicle's user accessible USB ports. This then forces the vehicle designer to choose a limited number of the many USB ports in the vehicle to support the OTG function and run dedicated USB cables to them. This can lead to user confusion and dissatisfaction since only certain consumer ports support the required functionality. Also, ports that support OTG may be co-located with other physically identical ports that do not. If the user chooses the wrong one, the applications they desire to run from the consumer device that requires USB Host mode won't work.

Another possible solution is to implement custom USB hubs wherein the USB Hub is able to dynamically swap its upstream port with one it's downstream ports when commanded to do so. System solutions built with this concept still require OTG controllers in the head unit but benefit from the fact that no additional wires need to be installed in the car. The existing USB cable between the USB OTG Host and the USB Hub can facilitate the necessary USB communications between the USB OTG controller in the Head Unit (HU) and a consumer device in USB Host (such as a smart phone). This solution also has some disadvantages however. For example, when the USB Hub is commanded to swap its upstream port with a downstream port, all other downstream ports of the USB Hubs lose their data connection with the Head Unit. While in this mode the Head Unit access to the other downstream ports of the hub cease. This may prevent use of certain vehicle system functions such as navigation or audio playback that may need consistent access to the other downstream ports of the hub to function. Furthermore, it requires the HU to have an available USB OTG port and a signaling path to control the hub upstream/downstream port configuration.

SUMMARY

An object of an embodiment of the present invention is to provide a system which is configured to enable a vehicle's embedded USB Host system to connect to mobile devices through a USB Hub, regardless of whether the mobile devices are configured to act as USB Hosts or USB Devices, without the need to provide OTG or dual role controllers in the head unit and without the need to provide additional cabling in the vehicle. Preferably, no hardware changes are required to be made to the USB Host circuits in the HU.

An embodiment of the present invention provides a system which can be employed between a vehicle's embedded USB Host and at least one, but preferably multiple, consumer facing USB ports provided in the vehicle for connection to consumer devices. The system is configured to recognize and control whether the consumer device is required to be connected to each USB port as a USB Host or as a USB Device. Further, the system is able to dynamically switch the device connection between USB Device mode and USB Host mode when desired. In the case where the consumer device is acting as a USB Device, signals are routed normally through a USB Hub to the Head Unit. In the case where the consumer device is acting as a USB Host, signals between the consumer device and the vehicle's embedded USB Host are routed and processed through a USB Host to Host Bridge which is connected to the USB Hub, thereby rendering the consumer device compatible with the vehicle's embedded USB Host.

The present invention is capable of being implemented in several different embodiments. For example, an embodiment of the present invention comprises a USB Hub Module having a USB Hub, USB Bridge, and USB routing switches implemented as discrete devices. The USB Hub upstream port is configured to be connected to a vehicle's embedded USB Host (such as a USB Host in a Head Unit). The USB Hub Module also includes a switching device (such as USB analog multiplexing switches for example) that is configured to route each consumer port to either the Bridge or the Hub. The USB Bridge is configured to effectively control the switching device. The USB Bridge is configured, based on signals from the Head Unit, whether the consumer device which is connected to the USB port is acting as USB Host or USB Device. In the case where the consumer device is acting as USB Host, the USB Bridge controls the switching device to route the USB port to the Bridge. The Bridge processes the signals from the consumer device and provides them to the USB Hub, thereby rendering the consumer device compatible with the vehicle's embedded USB Host. In the case where the consumer device is acting as USB Device, the USB Bridge controls the switching device such that the switching device provides the signals to the USB Hub, effectively bypassing the Bridge.

Still another embodiment of the present invention provides that the USB routing logic, USB Bridge, and USB Hub are integrated in a single combination USB Hub/USB Bridge Integrated Circuit (IC).

Still other embodiments are entirely possible, some of which are described and illustrated herein. For example, the concept can be extended to include additional embedded USB Device functions such as USB HID and USB Audio. Further it is also envisioned that all consumer facing USB ports of the Hub Module can emulate or otherwise support

dual role USB capability provided that each downstream port has a Bridge to support USB Host mode for the connected device and a direct connection to the USB Hub to support USB Device mode. In all cases, compliance to USB protocols and architectures is preferably maintained.

BRIEF DESCRIPTION OF THE DRAWINGS

The organization and manner of the structure and operation of the invention, together with further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawings wherein like reference numerals identify like elements in which:

FIG. **1** illustrates a system wherein a multiple port self-powered USB Hub functions to connect a single USB Host to a plurality of USB ports;

FIG. **2** illustrates a system wherein a self-powered USB Hub provides not only a plurality of USB ports, but also a Secure Digital ("SD") card reader;

FIG. **3** illustrates a vehicle infotainment system structure wherein multiple USB Hubs are connected together or tiered, such that USB Hubs feed other USB Hubs;

FIG. **4** illustrates a system which is in accordance with an embodiment of the present invention, wherein a USB Hub, USB Bridge and a switching device are provided as discrete components;

FIG. **5** illustrates a system which is in accordance with an alternative embodiment of the present invention, wherein USB routing/switching logic and a USB Bridge are integrated with a USB Hub in a combination USB Hub/USB Bridge Integrated Circuit (IC);

FIG. **6** illustrates the different components of the combination USB Hub/Bridge IC shown in FIG. **5**;

FIG. **7** illustrates one possible endpoint configuration of the USB Bridge shown in FIGS. **5** and **6**; and

FIG. **8** illustrates an example implementation of a Head Unit Software Architecture.

DESCRIPTION OF ILLUSTRATED EMBODIMENTS

While this invention may be susceptible to embodiment in different forms, there are specific embodiments shown in the drawings and will be described herein in detail, with the understanding that the present disclosure is to be considered an exemplification of the principles of the invention, and is not intended to limit the invention to that as illustrated.

FIG. **4** illustrates a system which is in accordance with an embodiment of the present invention. The system is configured to effectively render a vehicle's embedded USB Host compatible with consumer devices which are configured to also act as USB Host or USB Device. The system is in the form of a self-powered USB Hub Module having a USB, a USB Bridge, and a switching device implemented as discrete devices. The USB Hub is preferably provided in the form of an integrated circuit (IC), and is configured (via an upstream USB port) connected to a vehicle's embedded USB Host (such as a USB Host in a Head Unit) via vehicle internal wiring, such as, in one embodiment, via a single USB data cable between the Head Unit and USB Hub. The USB Hub also includes a plurality of downstream USB ports, at least one of which is connected to a USB Bridge (which also is preferably provided in the form of an integrated circuit (IC)). At least one downstream USB port of the USB Hub is connected to a switching device (such as USB analog multiplexing switches, for example). The

switching device is configured to be connected to at least one USB port in the vehicle for connection to a consumer device. The USB Bridge is configured to effectively control the switching device although other control mechanisms are envisioned. The USB Hub Module is configured such that signals received from at least one USB port are received by the switching device, and the switching device routes the signals to the USB Bridge or the USB Hub. In the case where the consumer device is acting as USB Host, the USB Bridge processes the USB packets from the consumer port and provides them to the USB Hub, thereby rendering the consumer device compatible with the vehicle's embedded USB Host. In the case where the consumer device is acting as USB Device, the USB Bridge controls the switching device such that the switching device provides the USB signaling directly to the USB Hub, bypassing the Bridge.

As shown in FIG. **4**, the system also includes Power Management structure, as well as some other conventional structure not specifically shown in FIG. **4**, but which would be readily assumed to be present by one having ordinary skill in the art.

In use, the Head Unit controls the switching device via the USB Bridge hardware or any other convenient means of control. The HU software application may choose to enable, for example, a phone on any one of the consumer USB ports, by requesting, commanding or otherwise knowing the phone is required to be in USB Host mode and commanding the routing of the specific USB port the phone is attached to the USB Bridge. Once routed to the USB Bridge, the phone will detect a USB Device is connected and the phone will begin the standard USB enumeration sequence. The detection and enumeration processes are defined by USB standards and not explained here in detail. However, for purposes of describing the operation of the invention, a general understanding is provided herein. The enumeration process follows a strict sequence of USB descriptor requests from the USB Host and USB descriptor responses from the USB Device that allow the Host to determine the capabilities and functions of the Device and configure the USB Device for operation. Once the complete set of device descriptors are known the USB Host will then load the appropriate USB driver(s) and applications to support in the functionality that the USB Device provides. In the scope of this invention it is envisioned that the responses to the descriptor requests made by the phone (USB Host) are either answered locally by the Bridge or preferably, the requests are forwarded through the Bridge to the Head Unit where its device drivers process the request and return the response. The descriptor responses from the device driver are conveyed to the USB Bridge, which then, in turn, passes them to the phone. By passing descriptor request to the Head Unit drivers and returning the responses from the Head Unit drivers back to the consumer device, the Bridge appears as a transparent component in the USB system architecture. The system capabilities are controlled by the Head Unit and the system remains flexible without need for changes to the Bridge firmware or hardware when the system designer requires changes to the descriptor responses. Once the consumer device completes the enumeration process, the Head Unit's USB functional capabilities are known to the consumer device and the consumer device may enable use of those functions over USB communication. At this point, the consumer device or the Head Unit may begin activating any number of supported services such as data connections, streaming audio and streaming video to and from the vehicle via the USB Bridge.

Another embodiment of the present invention can be provided, wherein the bridge is configured to act as an OTG port thus negating the need for switches and/or routing logic. In this case there would exist one Bridge functional block for each downstream port. This embodiment would effectively be a more generalized case of the example illustrated in FIG. **4**. FIG. **4** shows just one Bridge that any one of the consumer USB ports can be routed to. With just one bridge, only one consumer USB port can be connected to a USB host at a time. However, if each downstream port of the Hub has a dedicated Bridge, then multiple consumer ports can support connection to USB Host devices at the same time. Thus, any consumer port can be in either USB Host or USB Device mode at any time independently of the others.

FIG. **5** illustrates an alternative embodiment wherein the switching device comprises USB routing logic, and both the USB routing logic and the USB Bridge are integrated with the USB Hub in a combination USB Hub/USB Bridge Integrated Circuit (IC). This configuration has cost and size advantages over building it with discrete components connected together on a printed circuit board.

FIG. **6** illustrates the internal components of the USB Hub/USB Bridge Integrated Circuit (IC) shown in FIG. **5**. As shown, preferably the components of the USB Bridge include a bridge controller as well as endpoint buffers. While the exact configuration of endpoints is effectively up to the system designer to choose for a particular need, a specific example of one possible endpoint configuration is shown in FIG. **7**; however, many others are possible.

As shown in FIG. **7**, the endpoints of the Bridge may be designed to support multiple pipes of Bulk USB data connections between the Host A (Head Unit) and Host B (consumer device). In the Bridge, the IN endpoints of Device A are connected to the OUT endpoints of Device B and the OUT endpoints of Device A are connected to the IN endpoints of Device B. The design of the Bridge may be such that the data flow between the endpoints may be direct or buffered. For example, in the case of direct connection, once a USB packet is received from Host A on a Device A OUT endpoint, the internal logic of the Bridge moves to packet to the Device B IN endpoint if it is available. If Device B IN endpoint is full or otherwise not available then subsequent attempts of Host A to send more packets to Device A in the Bridge will be rejected until such time that the Device B IN endpoint is clear and the contents of the Device A OUT buffer is moved to it. Alternatively, there may exist a local buffer in the Bridge between the endpoints of Device A and B. For example, packets received on an OUT endpoint of Device A are placed in a local memory device for temporary storage until Device B IN endpoint is ready for them. The OUT endpoints are thus capable of receiving multiple packets from the Host until the buffer is full. Likewise the IN endpoints may, at times, transmit multiple packets until the buffer is empty. Such buffers are not required, but are envisioned, to improve system throughput performance in certain circumstances where one of the USB Hosts is occasionally busy and not keeping up with USB transactions at the same rate as the other USB Host. Regardless of the buffer configuration, the Bridge hardware has IN and OUT endpoints on Device A mapped to OUT and IN endpoints respectively on Device B, thus forming a bidirectional bridge that passes USB traffic between two USB Hosts with bandwidth sufficient to support the application requirements of the system.

Also shown in FIG. **7**, Device A and Device B provide a bidirectional Control endpoint connected to their respective USB Hosts. Control endpoints are required per USB standard to support USB defined control messages between the Host and Device both during and after the enumeration sequence. Optionally, USB endpoints may also be utilized per USB standard to employ messages intended to control user defined custom device specific behavior, referred to as Vendor Specific messages. As can be seen in FIG. **7**, the Control endpoints are mapped to the Bridge Controller (BC). The BC logic may be implemented in hardware or preferably software. The BC provides the capability to send, receive and process USB standard Control endpoint messages as well as vendor specific messages essential to the control and operation of the Bridge. At system startup, the A Host requests and receives descriptors from the BC via the Control endpoint. Once complete, Host A then loads the Bridge Driver in its software stack and configures the custom Bridge hardware for operation. Host A can then control the functions of the Bridge, such as USB switch routing control. The system is now ready to accept connection with USB Host mode consumer devices on the B Device of the Bridge. When such a connection is made, the BC will notify the Bridge Driver in Host A by sending a message on the control endpoint to Host A. Further, Host B will begin sending descriptor requests on the control endpoint to Device B in Bridge. The BC receives theses requests, encapsulates them with information that identifies them as descriptor requests from Host B and passes them to the Bridge Driver on Host using the control endpoint. Host A Bridge Driver receives these requests, identifies them as descriptor requests and passes the requests on to other software components in Host A system and waits for the descriptor responses. The descriptor responses are encapsulated by the Bridge driver to indicate they are descriptor responses that are to be forwarded to Host B. The response is then sent to the BC via the control endpoint. The BC receives them, identifies them as descriptor responses that should be forwarded to Device B and places them on the control endpoint for Device B. This process of receiving and forwarding messages back and forth between the two hosts continues until the enumeration process is complete with Host B. From that point on the two hosts may begin to use the IN and OUT endpoints to transfer application data and services over the bulk endpoints.

FIG. **8** illustrates one possible configuration of the system architecture including software components in the Head Unit interfacing with the Bridge/Hub. There are multiple ways that the operating system and software architecture can be constructed to support the functions of the USB Bridge/Hub. In FIG. **8**, a typical Linux implementation is shown including the Bridge/Hub Module and the Head Unit. The system design utilizes standard Linux Kernel components and configurations and should be familiar to those skilled in the art. The Head Unit USB Host Controller hardware is driven by the Host Controller Driver. The Host Controller Driver is connected to the USB Core. The USB Core connects the HCD with the standard USB Linux Device Drivers and the custom Bridge Driver. The Bridge Driver is configured to optionally connect directly to the User Space Application software or to the USB Gadget Driver depending on system architecture. The custom Bridge Driver plays a dual role of both controlling the functions of the Bridge hardware as well as providing a data path between the gadget device drivers and applications running on the Head Unit. The architecture illustrated is capable of handling both the operation and data paths associated with the Bridge and the Hub at the same time, thus allowing concurrent operation of consumer devices operating in USB Device mode with consumer devices operating in USB Host mode. In one

embodiment, the Hub/Bridge supports simultaneous active USB data connections between the Head Unit and multiple consumer devices, at least one of which being in host mode while the others are in device mode. In another embodiment, the Hub/Bridge supports simultaneous active USB data connections between the Head Unit and some combination of embedded and consumer USB devices along with at least one device being in host mode. While it is understood that the software functions of the head unit are essential to building a complete system, the designs of which can vary significantly and this example is provided only as a means of demonstrating one way to utilize the functionality of the present invention.

What is claimed is:

1. A method, comprising:

providing efficient communications among USB components of a data communication system that includes a first input port, a second input port, a USB hub, a USB bridge connected to the USB hub, an embedded USB host connected to the USB hub, a USB port connected to a USB device capable of operating in a USB Host mode and a USB device mode, and USB multiplexing switches connected to the USB port, the USB hub, and the USB bridge;

receiving a first USB signal from the USB device via the USB port while the USB device is operating in the USB host mode;

routing the first USB signal via the USB multiplexing switches from the USB device to the embedded USB host through the USB bridge and the USB hub;

receiving a second USB signal from the USB device via the USB port while the USB device is operating in the USB device mode; and

routing the second USB signal via the USB multiplexing switches from the USB device to the embedded USB host through the USB hub, wherein the second USB signal from the USB device to the embedded USB host bypasses the USB bridge.

* * * * *

EXHIBIT F

USB4912

USB2.0 Hi-Speed Automotive Hub

Status: In Production.

Documentation

Recommended for Automotive Design

Contact Us

The Microchip USB4912 is a USB2.0 Hi-Speed Hub with unique Smart Hub features targeted to automotive consumer ports and head unit applications. The USB4912 is compliant with the USB 2.0 Specification and has passed AEC-Q100 testing. This highly integrated chip optimizes board area and reduces overall system costs, with the incorporation of leadership functionality, including; Multi-Host Endpoint Reflector, battery charging support for industry profiles, embedded 32 bit micro-controller for the implementation of USB IO bridging and USB Power Delivery. The multiple downstream USB ports support USB2.0 Low Speed/Full Speed/Hi-Speed with a single USB2.0 Hi-Speed upstream port for host connection.

The Multi-Host Endpoint Reflector employs patented technology such that USB data is 'mirrored" between two USB hosts (Multi-Host) in order to execute USB transactions. This capability is fundamental in delivering architectures for smart phones that require host / device swapping in order to set-up an automotive session, including graphic user interface, from the mobile device to the head unit display.

Standard USB drivers, which are native to the operating system, including the CDC/NCM class driver, are utilized to execute device operation. No custom drivers are required. The Multi-Host Endpoint Reflector is considered a USB controller that is integrated in

datasheet and application notes.

Collapse

Product Features

- USB2.0 Hi-Speed Hub 1 Upstream port for USB Host connection 1 downstream ports with dual role (host/device) physical interfaces 1 Non-removable port for cascading hubs or attaching card reader device
- 1 Upstream port for USB Host connection
- 1 downstream ports with dual role (host/device) physical interfaces
- 1 Non-removable port for cascading hubs or attaching card reader device
- Patented Multi-Host Endpoint Reflector
- Device features to enable smart phone automotive sessions with head unit display
- USB Battery Charging, revision 1.2, support on downstream ports (DCP, CDP, SDP)
- Battery charging support for China and Apple profiles
- USB to I2C, SPI, and GPIO Apple authentication support
- Apple authentication support
- Interfaces to Microchip UPD350, Power Delivery Interface device
- SPI Flash provides flexibility for specification revisions and evolving system needs
- MultiTRAK Dedicated transaction translator per port
- Dedicated transaction translator per port
- PortMap Configurable port mapping and disable sequencing
- Configurable port mapping and disable sequencing
- PortSwap Configurable differential intra-pair signal swapping
- Configurable differential intra-pair signal swapping
- PHYBoost
- Programmable USB receiver sensitivity
- USB Link Power Management (LPM) support
- Vendor Specific Messaging (VSM) support
- Enhanced OEM configuration options available through external straps, OTP configuration or SMBus Slave Port
- 3.3V supply voltage
- 40-pin (5 x 5mm) VQFN

- GPS systems
- Infotainment systems
- Advanced instrumentations and controls
- LCD Monitors
- Multi-function USB Peripherals
- Embedded Automotive Systems
- Host to Host applications via Ethernet / NCM communication
- Media Hubs

Collapse

Parametrics

Upstream Port	USB 2.0
USB Speed	Hi-Speed
Downstream Ports	2
MGMT I/F	I2C
ROM I/F	SPI, I2C for OTP
Op Voltage (V)	3.3
MultiTRAK Tech	No
Per-Port Switching	Yes
Integrated Flash Media Reader	No
Port Map	Yes
Port Swap	Yes

Temp. Range Max.	85

All Application Notes

Embedded Software

Title	Download	Link
MPLAB® Connect Configurator - Programming and Configuration Utility		Link

RoHS Information

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EXHIBIT G

MICROCHIP

Overview Features Software RoHS Information Purchase

USB4914

Status: In Production.

Documentation

Recommended for Automotive Design

Contact Us

The Microchip USB4914 is a USB2.0 Hi-Speed Hub with unique Smart Hub features targeted to automotive consumer ports and head unit applications. The USB4914 is compliant with the USB 2.0 Specification and has passed AEC-Q100 testing. This highly integrated chip optimizes board area and reduces overall system costs, with the incorporation of leadership functionality, including; Multi-Host Endpoint Reflector, battery charging support for industry profiles, embedded 32 bit micro-controller for the implementation of USB IO bridging and USB Power Delivery. The multiple downstream USB ports support USB2.0 Low Speed/Full Speed/Hi-Speed with a single USB2.0 Hi-Speed upstream port for host connection.

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Collapse

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- 2 downstream ports with dual role (host/device) physical interfaces
- 1 Non-removable port for cascading hubs or attaching card reader device
- Patented Multi-Host Endpoint Reflector
- Device features to enable smart phone automotive sessions with head unit display
- USB Battery Charging, revision 1.2, support on downstream ports (DCP, CDP, SDP)
- Battery charging support for China and Apple profiles
- Apple authentication support
- I2S for audio support; Asynchronous In, Adaptive Out, 48KHz, two channel (16 bits/channel)
- Flexible I2S capabilities via firmware update
- 32 bit, embedded microcontroller in the hub executes PD stack and system policy manager
- Interfaces to Microchip UPD350, Power Delivery Interface device
- Power delivery stack runs from external SPI Flash
- SPI Flash provides flexibility for specification revisions and evolving system needs
- Dedicated transaction translator per port
- Configurable port mapping and disable sequencing
- Configurable differential intra-pair signal swapping
- PHYBoost
- Programmable USB receiver sensitivity
- USB Link Power Management (LPM) support
- Vendor Specific Messaging (VSM) support
- Enhanced OEM configuration options available through external straps, OTP configuration or SMBus Slave Port
- 3.3V supply voltage
- 48-pin (7x7mm) SQFN
- 48-pin (7x7mm) Wettable Flanks VQFN

- Advanced instrumentations and controls
- LCD Monitors
- Multi-function USB Peripherals
- Embedded Automotive Systems
- Host to Host applications via Ethernet / NCM communication

Collapse

Parametrics

Upstream Port	USB 2.0
USB Speed	Hi-Speed
Downstream Ports	3
MGMT I/F	I2C
ROM I/F	SPI, I2C for OTP
Op Voltage (V)	3.3
MultiTRAK Tech	No
Per-Port Switching	Yes
Integrated Flash Media Reader	No
Port Map	Yes
Port Swap	Yes
True Speed	No
PHY Boost	Yes

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MPLAB® Connect Configurator - Programming and Configuration Utility		Link

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EXHIBIT H

USB4916

Status: In Production.

Documentation

Recommended for Automotive Design

Contact Us

The Microchip USB4916 is a USB2.0 Hi-Speed Hub with unique Smart Hub features targeted to automotive consumer ports and head unit applications. The USB4916 is compliant with the USB 2.0 Specification and has passed AEC-Q100 testing. This highly integrated chip optimizes board area and reduces overall system costs, with the incorporation of leadership functionality, including; Multi-Host Endpoint Reflector, battery charging support for industry profiles, embedded 32 bit micro-controller for the implementation of USB IO bridging and USB Power Delivery. The multiple downstream USB ports support USB2.0 Low Speed/Full Speed/Hi-Speed with a single USB2.0 Hi-Speed upstream port for host connection.

The Multi-Host Endpoint Reflector employs patented technology such that USB data is 'mirrored" between two USB hosts (Multi-Host) in order to execute USB transactions. This capability is fundamental in delivering architectures for smart phones that require host / device swapping in order to set-up an automotive session, including graphic user interface, from the mobile device to the head unit display.

Standard USB drivers, which are native to the operating system, including the CDC/NCM class driver, are utilized to execute device operation. No custom drivers are required. The Multi-Host Endpoint Reflector is considered a USB controller that is integrated in

datasheet and application notes.

Collapse

Product Features

- 1 Upstream port for USB Host connection
- 4 downstream ports with dual role (host/device) physical interfaces
- 1 Non-removable port for cascading hubs or attaching card reader device
- Patented Multi-Host Endpoint Reflector
- Device features to enable smart phone automotive sessions with head unit display
- USB Battery Charging, revision 1.2, support on downstream ports (DCP, CDP, SDP)
- Battery charging support for China and Apple profiles
- Apple authentication support
- I2S for audio support; Asynchronous In, Adaptive Out, 48KHz, two channel (16 bits/channel)
- Flexible I2S capabilities via firmware update
- 32 bit, embedded microcontroller in the hub executes PD stack and system policy manager
- Interfaces to Microchip UPD350, Power Delivery Interface device
- Power delivery stack runs from external SPI Flash
- SPI Flash provides flexibility for specification revisions and evolving system needs
- Dedicated transaction translator per port
- Configurable port mapping and disable sequencing
- Configurable differential intra-pair signal swapping
- PHYBoost
- Programmable USB receiver sensitivity
- USB Link Power Management (LPM) support
- Vendor Specific Messaging (VSM) support
- Enhanced OEM configuration options available through external straps, OTP configuration or SMBus Slave Port
- 3.3V supply voltage
- 64-pin (9x9mm) SQFN
- 64-pin (9x9mm) Wettable Flanks VQFN Target Applications:

- Advancd instrumentations and controls
- LCD Monitors
- Multi-function USB Peripherals
- Embedded Automotive Systems
- Host to Host applications via Ethernet / NCM communication

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Parametrics

Upstream Port	USB 2.0
USB Speed	Hi-Speed
Downstream Ports	5
MGMT I/F	I2C
ROM I/F	SPI, I2C for OTP
Op Voltage (V)	3.3
MultiTRAK Tech	Yes
Per-Port Switching	Yes
Integrated Flash Media Reader	No
Port Map	Yes
Port Swap	Yes
True Speed	No
PHY Boost	Yes

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Embedded Software

Title	Download	Link
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EXHIBIT I

2016 AUTOMOTIVE NEWS PACE AWARDS

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DUAL ROLE HUB

Delphi Automotive

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Judge's Citation: When Apple announced CarPlay™, iPhone users couldn't wait to buy a car with an infotainment interface that was intuitive and mirrored how their IPhone worked. The problem with the CarPlay™ integration came when a driver wanted to access music on another device, play video on a passenger's tablet or listen to music on a passenger's Android phone. The iPhone running CarPlay™ wanted to operate as the sole "host" device taking control from the car radio and denying access to other devices. Delphi solved it – at a lower cost, in a smaller package and with all functionality - by developing a custom USB ASIC chip, allowing the iPhone and car radio to be recognized as "host" devices simultaneously.

Delphi's Dual Role Hub solved this vexing problem by developing a" Smart Media USB Hub", that allows not just only a single Apple device, but allows any device plugged into the multi-port hub system to be a "host." Now one passenger can watch a movie on an SD card, while another watches a movie off a handheld, while the driver uses the system for navigation, phone conversations, or just listens to their music. Delphi developed an amazingly elegant and cost effective solution for a complicated problem in the world of vehicle infotainment systems.

Delphi will capture 40 percent of GM, Ford, and Chrysler products globally, representing 10 million units and their technology is ready to reach every OEM around the globe!

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EXHIBIT J

MICROCHIP

AN2374

USB4916/USB4914 Multi-Host Endpoint Reflector Operation

Author: *Andrew Rogers*
Microchip Technology Inc.

INTRODUCTION

The internal Multi-Host Endpoint Reflector in the Microchip USB4916 and USB4914 hubs allows for smart-phone automotive mode sessions to be entered on the downstream ports.

The USB4916 supports the Multi-Host Endpoint Reflector on four downstream ports.

The USB4914 supports the Multi-Host Endpoint Reflector on two downstream ports.

The Multi-Host Endpoint Reflector uses standard Network Control Model (NCM) device protocol, which is a sub-class of Communication Device Class (CDC) group of protocols. Standard NCM USB drivers may be utilized; No custom drivers are required.

A Multi-Host Endpoint Reflector session may be entered on only 1 downstream port at a time. Entry into Multi-Host mode is initiated via a no data Control USB transfer addressed to the internal Multi-Host Endpoint Reflector device in the hub.

Sections

References

Consult the following documents for details on the specific parts referred to in this document.

- *Microchip USB4914 Data Sheet*
- *Microchip USB4916 Data Sheet*
- *Microchip Configuration Options for the USB4715 and USB49xx Application Note*

1.0 FUNCTIONAL OVERVIEW

The internal block diagrams of Microchip USB4914 and USB4916 are shown below in Figure 1 and Figure 2 respectively.

Both USB4914 and USB4916 have two internal USB devices. The Multi-Host Endpoint Reflector device is a Composite WinUSB and NCM device with Product ID 0x4910. The Hub Feature Controller device which enables USB bridging function is a WinUSB device with Product ID 0x4940.

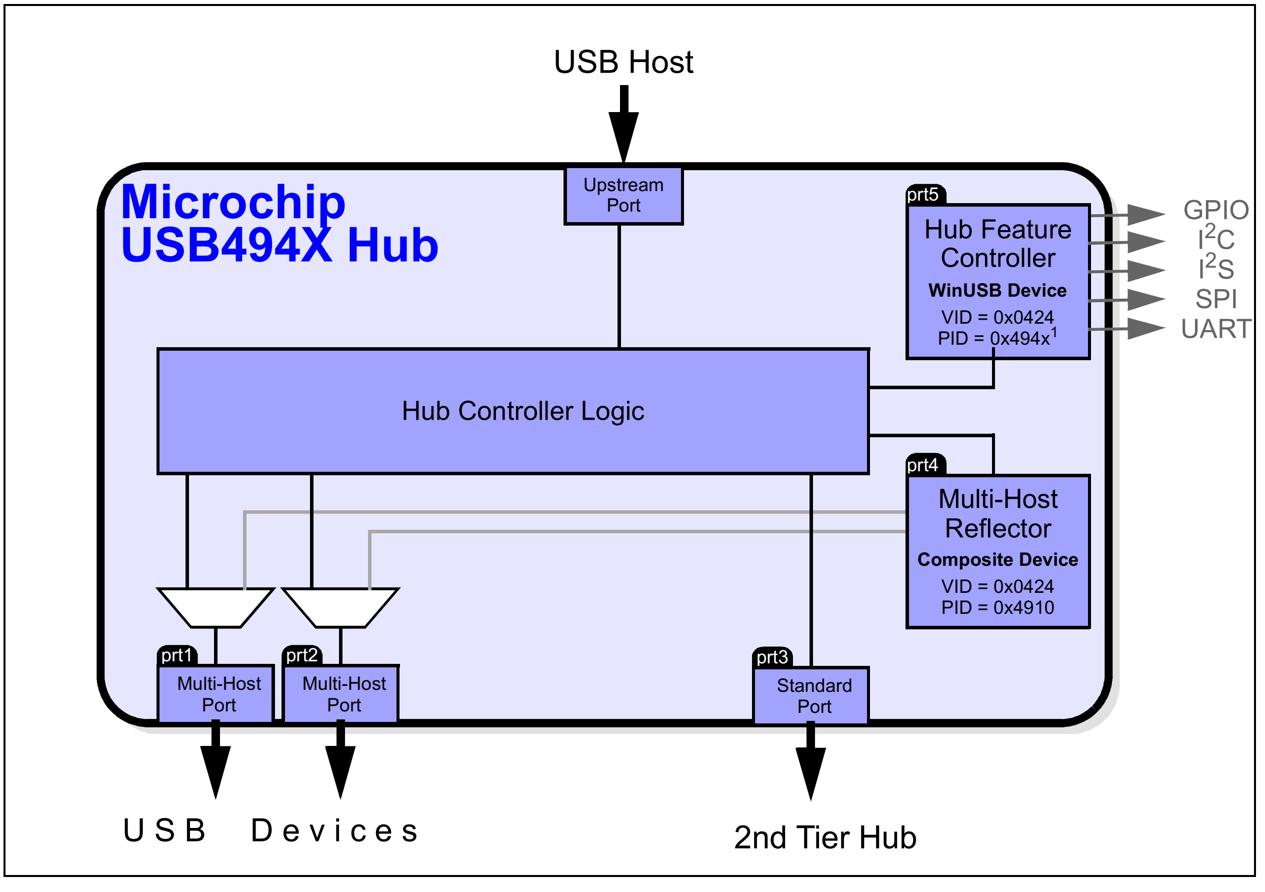
On the USB4914, the Multi-Host Endpoint Reflector is connected to port 4, while the Hub Feature Controller is connected to port 5.

On the USB4916, the Multi-Host Endpoint Reflector is connected to port 6, while the Hub Feature Controller is connected to port 7.

The hub ports which are connected to both the Multi-Host Endpoint Reflector and Hub Feature Controller are both configured as non-removable.

Note:	The Multi-Host Endpoint Reflector device only attaches after a specific USB command is issued from the USB host to the Hub Feature Controller to enter the automotive mode.

FIGURE 1: USB494X INTERNAL BLOCK DIAGRAM



Note 1: PID value will change depending on the specific configuration of the Hub Feature Controller.

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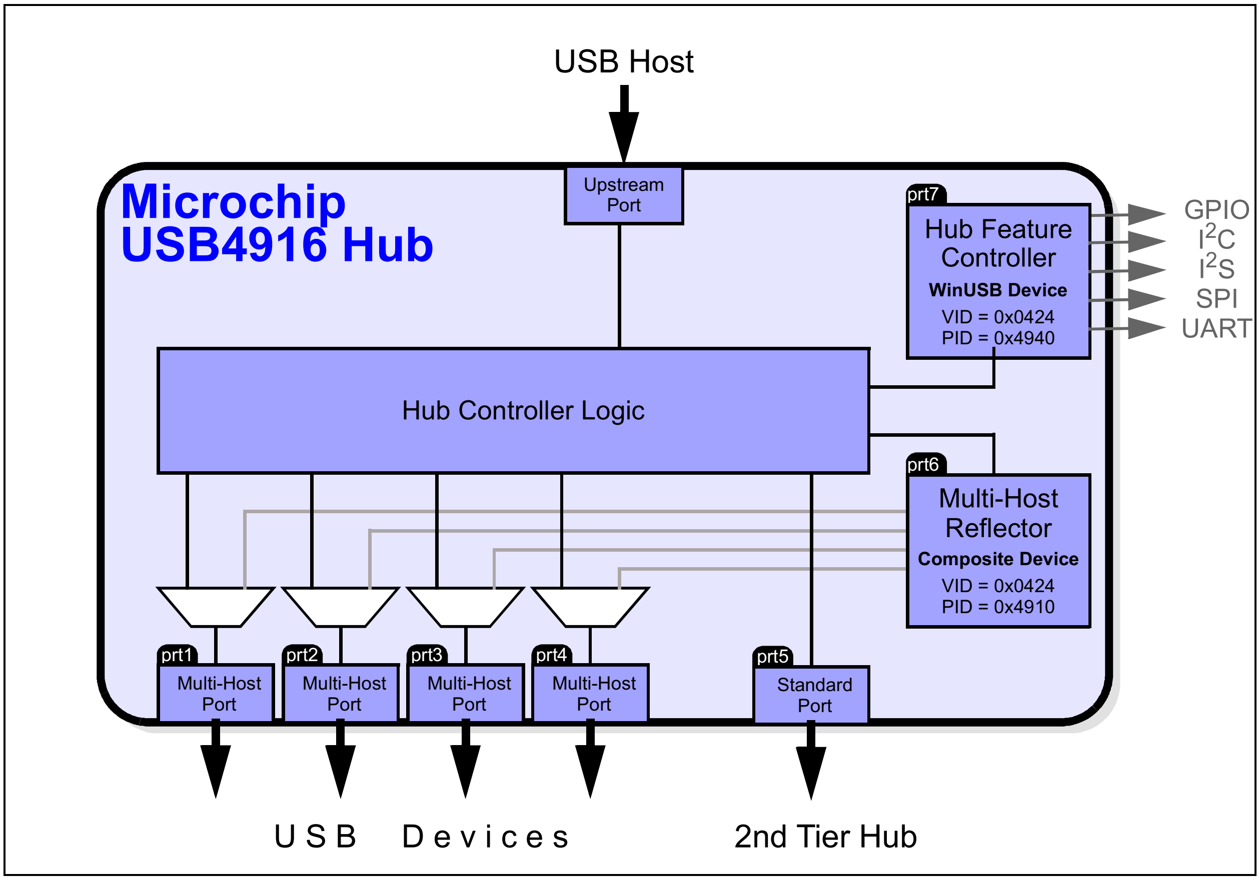
FIGURE 2: USB4916 INTERNAL BLOCK DIAGRAM



1.1 Multi-Host Automotive Session

A Multi-Host automotive session is initiated via a USB command to the Hub Feature Controller internal device. The details of this USB command are shown in Section 3.0, Multi-Host Command Details, and a example USB protocol trace capture of the command is detailed in section Section 4.0, Multi-Host Command Example.

The USB4914 supports the Multi-Host Endpoint Reflector operation on downstream ports one and two.

The USB4916 supports the Multi-Host Endpoint Reflector operation on downstream ports one through four.

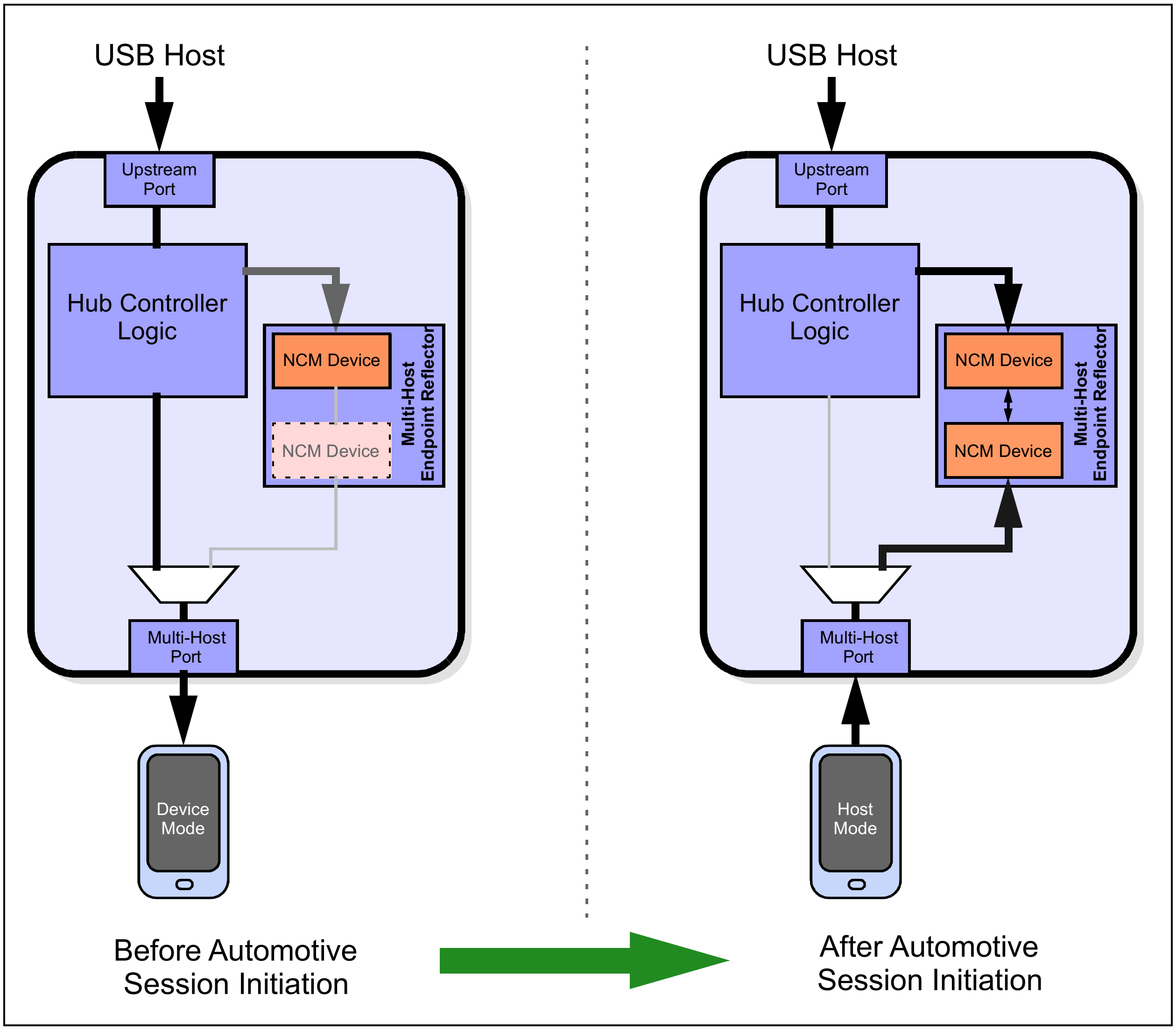
When a Multi-Host session is initiated with one of the Multi-Host capable downstream ports, the device port is multiplexed over to the Multi-Host Endpoint Reflector device and the NCM class Multi-Host Endpoint Reflector device attaches.

A typical sequence of events for automotive session initialization is:

1. The automotive head unit (USB Host) enumerates a smartphone on Multi-Host capable port “X” and recognizes that it is capable of an automotive session.
2. The automotive head unit sends any necessary commands to the smartphone in order to set that device into the automotive mode.
3. The automotive head unit sends the Multi-Host command to the internal Hub Feature Controller device Endpoint 0 to enter the Multi-Host Endpoint Reflector mode with port “X”.
4. The automotive head unit will see the smartphone disconnect from port “X”.
5. The smartphone will switch to Host mode operation and will see an NCM class device attach. The smartphone will enumerate this device and discover it as an NCM class device.
6. Data can now be exchanged between the automotive head unit and the smartphone device while both are operating as a USB host through the NCM class device endpoints.

Figure 3 below shows the internal connections made both before and after an automotive session is initiated.

FIGURE 3: MULTI-HOST ENDPOINT REFLECTOR



1.2 The Multi-Host Endpoint Reflector Composite Device

The internal Multi-Host Endpoint Reflector device is a composite device. A composite device is a collection of different USB device classes all connected to a single USB port.

There are three individual USB devices within the Multi-Host Endpoint Reflector composite device.

Device 1 - WinUSB device: The Multi-Host Endpoint Reflector session commands must be sent to this device

Device 2 - NCM/IAP Bridge Device (NCM Communications Interface)

Device 3 - NCM/IAP Bridge Device (NCM Data Interface)

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2.0 NCM DEVICE CLASS

2.1 NCM Device Specification

The Multi-Host Endpoint Reflector uses standard Network Control Model (NCM) device protocol, which is a sub-class of Communication Device Class (CDC) group of protocols. The “Universal Serial Bus Communications Class Subclass Specifications for Network Control Modules” Revision 1.0 which defines the NCM device class was released in Nov 2010. All major computing and mobile Operating Systems now natively include drivers for NCM support.

The NCM class specification can be obtained from www.usb.org

2.2 NCM Device Protocol

The NCM device class allows IEEE 802.3 Ethernet frames to be exchanged over USB protocol between USB hosts and USB devices. The Ethernet frames may convey either IPv4 (Internet Protocol version 4.0) and IPv6 (Internet Protocol version 6.0) datagrams.

The NCM specification builds upon the USB CDC specification for ECM to allow for improved data rates. ECM was designed for use with USB full-speed connections, but is not optimized for high-speed USB connections. The NCM device class protocol allows multiple Ethernet frames to be combined to single USB bulk transfers. NCM device functions may also specify preferences for Ethernet frame placement within a USB data transfer.

The NCM specification defines two ways of encapsulating and translating Ethernet datagrams to USB transfers. One for achieving full USB 2.0 (64KiB) data rates, and the other for USB 3.0 data rates. (4GiB). The 64KiB method intended for USB 2.0 use allows for up to forty 1514-byte Ethernet frames to be combined to one USB bulk transfer.

An NCM device implements two interfaces: an NCM Communications Interface and an NCM Data Interface. The Communications Interface is used for configuration and management of the networking functions. The Data Interface is used for transporting the bulk data payloads. A single NCM driver will manage both interfaces.

3.0 MULTI-HOST COMMAND DETAILS

The USB hub requires a specific USB command to be issued from the USB host to indicate when a Multi-Host Endpoint Reflector automotive session should begin.

The USB command is a NO DATA Control transfer which must be issued to Endpoint 0 of the internal Hub Feature Controller device (the WinUSB device). On USB4916, the Hub Feature Controller is the internal device located on Port 7. On USB4914, the Hub Feature Controller is the internal device located on Port 5.The SETUP command format is shown below in Table 1 and Table 2.

TABLE 1: MULTI-HOST ENDPOINT REFLECTOR SETUP PACKET

Setup Parameter	Value	Description
bmRequestType	0x41	Device-to-host, vendor class, targeted to interface
bRequest	0x90	SET_ROLE_SWITCH
wValue	0xYYYY	Bits detailed below
wIndex	0x0000	Reserved
wLength	00	No data

TABLE 2: WVALUE DETAIL OF MULTI-HOST ENDPOINT REFLECTOR SETUP PACKET

Bit	Name	Description
15:11	Reserved	Reserved (Must Always Be ‘0’)
10:8	ENUM_TIMEOUT	These bits control a timer which is started when the Multi-Host Endpoint Reflector command is sent. If the smartphone does not enumerate the NCM device before the timer expires, the hub will revert to the default state with wherein there is no active Multi-Host Endpoint Reflector automotive session. If the smartphone does enumerate the NCM device, then the Multi-Host Endpoint Reflector automotive session will remain active. 000 = No Timeout defined (hub will not automatically terminate Multi-Host End-point Reflector automotive session) 001 = 10 ms 010 = 100 ms 011 = 500 ms 100 = 1 second 101 = 5 seconds 110 = 10 seconds 111 = 20 seconds
7	Reserved	Reserved (Must Always Be ‘0’)
6:5	ROLE_SWITCH_-TYPE	Must always be ‘00’ for Multi-Host Endpoint Reflector

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TABLE 2: WVALUE DETAIL OF MULTI-HOST ENDPOINT REFLECTOR SETUP PACKET

Bit	Name	Description
4	ROLE_SWITCH_STATE	1 = Transitions the port defined in PORT bits in to Multi-Host Endpoint Reflector session 0 = Terminates Multi-Host Endpoint Reflector session currently active on port defined in PORT bits
3:0	PORT	Physical downstream port to initiate or terminate Multi-Host Endpoint Reflector session 0001 = Port 1 0010 = Port 2 0011 = Port 3 0100 = Port 4 All others = ***Invalid***

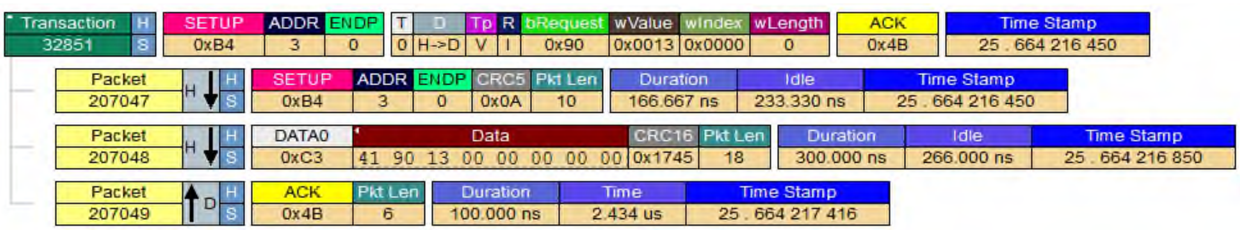
4.0 MULTI-HOST COMMAND EXAMPLE

An example of the Multi-Host Endpoint Reflector session initialization command for Port 3 is shown below. This command is sent to EP0 of the Hub Feature Controller.

TABLE 3: MULTI-HOST ENDPOINT REFLECTOR SETUP COMMAND EXAMPLE

Setup Parameter	Value	Note
bmRequestType	0x41	Device-to-host, vendor class, targeted to interface
bRequest	0x90	SET_ROUSB491XLE_SWITCH
wValue	0x0013	Bits 15:11 = 0000b Bits 10:8 = 000b (no enum timer) Bit 7 = 0b Bits 6:5 = 00b Bit 4 = 1b (Enter Multi-Host Endpoint Reflector session) Bits 3:0 = 0011b (Port 1)
wIndex	0x0000	Reserved
wLength	00	No data

FIGURE 4: REGISTER READ SETUP TRANSACTION EXAMPLE



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APPENDIX A: APPLICATION NOTE REVISION HISTORY

TABLE A-1: REVISION HISTORY

Revision Level & Date	Section/Figure/Entry	Correction
DS00002374A (05-08-17)	All	Initial release.

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